

AD-A095 928

AIR FORCE ENGINEERING AND SERVICES CENTER TYNDALL AF--ETC F/6 13/2  
SMALL CRATER EXPEDIENT REPAIR TEST.(U)

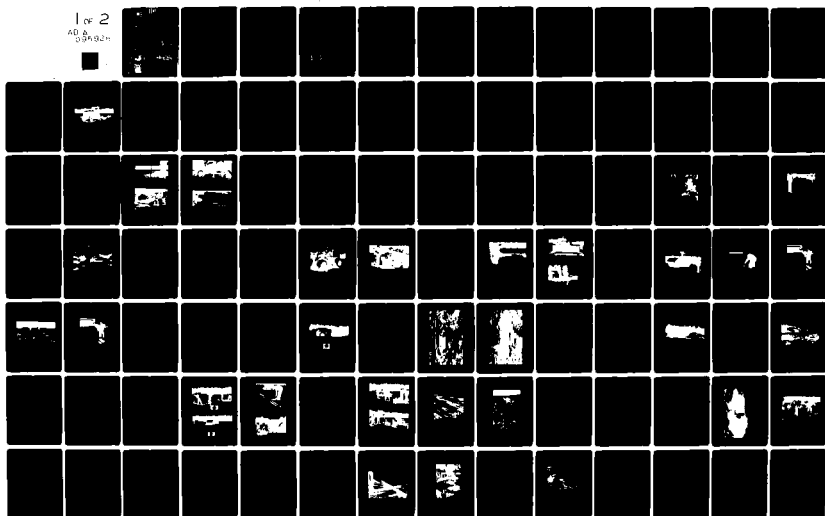
AUG 80 K J KNOX  
AFESC/ESL-YR-80-42

UNCLASSIFIED

NL

1 of 2

AD A  
095928



12 LEVEL II

ESL-TR-80-42

## SMALL CRATER EXPEDIENT REPAIR TEST

KENNETH J. KNOX  
ENGINEERING RESEARCH DIVISION

AUGUST 1980

FINAL REPORT  
JULY 1979 — AUGUST 1979

DTIC  
ELECTE  
S MAR 4 1981 D  
B

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED



AFEGSC

ENGINEERING & SERVICES LABORATORY  
AIR FORCE ENGINEERING & SERVICES CENTER  
TYNDALL AIR FORCE BASE, FLORIDA 32403

81 3 3 061

AD A 095928

DOC FILE COPY

NOTICE

Please do not request copies of this report from  
HQ AFESC/RD (Engineering and Services Laboratory).  
Additional copies may be purchased from:

National Technical Information Service  
5285 Port Royal Road  
Springfield, Virginia 22161

Federal Government agencies and their contractors  
registered with Defense Technical Information Center  
should direct requests for copies of this report to:

Defense Technical Information Center  
Cameron Station  
Alexandria, Virginia 22314

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

AFESC/REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESL-TR-80-42	2. GOVT ACCESSION NO. AD-A095928	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SMALL CRATER EXPEDIENT REPAIR TEST.		5. TYPE OF REPORT & PERIOD COVERED Final Report, July 1979 to August 1979.
7. AUTHOR(s) Kenneth J. Knox		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Engineering and Services Center Rapid Runway Repair Branch Tyndall Air Force Base, Florida 32403		8. CONTRACT OR GRANT NUMBER(s) 1261
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Engineering and Services Center Tyndall Air Force Base, Florida 32403		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS PE 63723F JON/2104-2B-22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE August 1980
		13. NUMBER OF PAGES 115
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES  Availability of this report is specified on reverse of front cover.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Temporary, Expedient Airfield Pavement Repair      Polymer-Concrete Bomb Damage Repair Unsurfaced Repairs Base Course Vibratory Compaction		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes actual field repairs of six small craters; four using unsurfaced crushed limestone compacted only from the surface with 10-ton vibratory rollers, and two repaired with hand-mixed polymer-concrete. Following the repairs the patches were trafficked with an F-4 loadcart. The crushed limestone method proved suitable for the repair of small craters; the hand-mixed polymer-concrete method was not suitable for repairs larger than approximately five feet in diameter (scabs).		

DD FORM 1 JAN 73 1473

UNCLASSIFIED  
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

394633

## PREFACE

This report was prepared by the Air Force Engineering and Services Center, Engineering and Services Laboratory at Tyndall Air Force Base, Florida, under Job Order Number 21042B22 Bomb Damage Repair Materials Field Test. Data from this test combined with data from earlier and subsequent tests will be used to write a comprehensive Small Crater Repair Manual. This work was accomplished during the period from July 1979 to August 1979.

This report discusses field tests of two previously identified small crater repair methods. This report discusses the use of materials for bomb damage repair. The report does not constitute an indorsement or rejection of these products for the Air Force nor can it be used for advertising a product.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public including foreign nationals.

This technical report has been reviewed and is approved for publication.

*Michael T. McNerney*  
MICHAEL T. McNERNEY, Capt, USAF  
Project Officer

*Robert E. Boyer*  
ROBERT E. BOYER, Lt Col, USAF  
Chief, Engineering Research  
Division

*Francis B. Growley III*  
FRANCIS B. GROWLEY, III, Col, USAF  
Director, Engineering and Services Laboratory

**DTIC**  
**ELECTE**  
**S** MAR 4 1981 **D**  
**B**

Accession For	
NTIS GRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
<b>A</b>	

## TABLE OF CONTENTS

Section	Title	Page
I.	INTRODUCTION . . . . .	1
1.	Background. . . . .	1
2.	Test Objectives . . . . .	2
3.	Approach. . . . .	2
II.	DESCRIPTION OF TESTS. . . . .	6
1.	Test Site . . . . .	6
2.	Crater Information. . . . .	6
3.	Equipment and Personnel . . . . .	11
4.	Repair Materials. . . . .	11
5.	Crushed Limestone Repair Procedures . . . . .	14
6.	Polymer-Concrete Repair Procedures. . . . .	20
7.	Repair Evaluation Procedures. . . . .	22
III.	ANALYSIS OF REPAIR PROCEDURES . . . . .	30
1.	Crushed Limestone Repair. . . . .	30
2.	Polymer-Concrete Repair . . . . .	55
3.	Time Analyses . . . . .	71

TABLE OF CONTENTS (CONCLUDED)

Section	Title	Page
IV.	ANALYSIS OF REPAIR QUALITY . . . . .	75
1.	Field Testing Results . . . . .	75
2.	F-4 Loadcart Testing Results . . . . .	76
3.	Repair Profile Analysis . . . . .	81
V.	CONCLUSIONS . . . . .	91
1.	General Conclusions . . . . .	91
2.	Procedures. . . . .	91
3.	Equipment . . . . .	92
VI.	RECOMMENDATIONS . . . . .	93
	REFERENCES. . . . .	94
APPENDICES		
A.	EQUIPMENT PERFORMANCE SPECIFICATIONS. . . . .	96
B.	CRUSHED LIMESTONE REPAIR TIME ESTIMATES . . . . .	100

# LIST OF FIGURES

Figure	Title	Page
1.	F-4 Loadcart . . . . .	3
2.	Traffic Pattern for F-4 Loadcart . . . . .	5
3.	Plan View of Test Site . . . . .	7
4.	Cross Section of Clay Core . . . . .	8
5.	Gradation of Wewahitchka Clay. . . . .	9
6.	Gradation of 1 1/2-inch Crushed Limestone. .	13
7.	Crushed Limestone Repair Sequence of Tasks .	16
8.	Crater Overfilled 6 inches with Crushed Limestone. . . . .	18
9.	Leveling Crushed Limestone with the Loader .	18
10.	Leveling Crushed Limestone with the Grader .	19
11.	Consolidation of Crushed Limestone at Edge of Concrete. . . . .	19
12.	Polymer-Concrete Repair Sequence of Tasks. .	21
13.	Time Sequence Log Form . . . . .	24
14.	Task Start and Finish Times Form . . . . .	25
15.	Troxler 3411B Nuclear Moisture-Density Gauge. . . . .	27
16.	Nuclear Moistures and Densities Log Form . .	28
17.	Profiling the Craters. . . . .	29
18.	Crater 1 . . . . .	31
19.	Work Flow Diagram - Crater 1 . . . . .	32

# LIST OF FIGURES (CONTINUED)

Figure	Title	Page
20.	Equipment Operation and Repair Tasks - Crater 1 . . . . .	33
21.	Compacting Debris Backfill with the Loader . . . . .	35
22.	Cleaning the Debris Around the Crater Edges. . . . .	36
23.	Checking for Upheaved Pavement . . . . .	38
24.	The Dozer Inside a Small Crater. . . . .	39
25.	Removing Upheaved Pavement with the Ripper Tooth. . . . .	39
26.	Compacting the Crushed Limestone . . . . .	41
27.	Concrete Spall Caused by the Vibratory Roller . . . . .	41
28.	Anchoring the T-17 Membrane FOD Cover. . . . .	42
29.	Crater 3 After Clearing of Debris . . . . .	43
30.	Work Flow Diagram - Crater 3 . . . . .	45
31.	Equipment Operation and Repair Tasks - Crater 3 . . . . .	46
32.	Towed Rotary Broom . . . . .	48
33.	Crater 5 . . . . .	50
34.	Crater 6 . . . . .	51
35.	Work Flow Diagram - Craters 5 and 6 . . . . .	52
36.	Equipment Operation and Repair Tasks - Craters 5 and 6. . . . .	53
37.	Dozer Too Small for Upheaval Removal . . . . .	54
38.	Crater 2 . . . . .	56

# LIST OF FIGURES (CONTINUED)

Figure	Title	Page
39.	Work Flow Diagram - Crater 2 . . . . .	57
40.	Equipment Operation and Repair Tasks - Crater 2 . . . . .	58
41.	Manually Cleaning the Crater Edges . . . . .	60
42.	Compacting and Leveling the Debris with the Vibratory Roller . . . . .	60
43.	Cleaning the Pavement Edges with the Air Compressor . . . . .	61
44.	Pallet of Silikal® . . . . .	61
45.	Leveling the Uniform Aggregate by Hand . . .	63
46.	Mixing and Placing the Polymer-Mortar. . . .	63
47.	Rough Polymer-Concrete Finish - Crater 2 . .	64
48.	Debris from Polymer Concrete Repair. . . . .	65
49.	Work Flow Diagram - Crater 4 . . . . .	67
50.	Equipment Operation and Repair Tasks - Crater 4 . . . . .	68
51.	Crater 4 . . . . .	69
52.	Two-Man Teams Mixing and Placing Silikal®. .	70
53.	Rutting Failure on Crater 1. . . . .	77
54.	Spalled Polymer Concrete - Crater 2. . . . .	78
55.	Quality Control Failure on Crater 4. . . . .	80
56.	Crater 1 Profiles. . . . .	82
57.	Crater 2 Profiles. . . . .	83
58.	Crater 3 Profiles (Before Maintenance). . .	84
59.	Crater 3 Profiles (After Maintenance) . . .	85

# LIST OF FIGURES (CONCLUDED)

Figure	Title	Page
60.	Crater 4 Profiles. . . . .	86
61.	Crater 5 Profiles. . . . .	87
62.	Crater 6 Profiles. . . . .	88
63.	Surface Roughness Measurements . . . . .	89
A-1.	International Harvester TD-20 Dozer. . . . .	97
A-2.	Fiat-Allis 745-C Loader. . . . .	98
A-3.	RayGo Rascal 410A Vibratory Roller . . . . .	99
B-1.	Crater Preparation Times for Crushed Limestone Repair . . . . .	101
B-2.	Times for Select Fill Delivery - Crushed Limestone Repair . . . . .	102
B-3.	Times to Place, Grade and Compact Select Fill for Crushed Limestone Repair. . . . .	103
B-4.	Determination of Times for Vibratory Compaction . . . . .	104

# LIST OF TABLES

Table	Title	Page
1	Crater Information. . . . .	10
2	Heavy Equipment Allocations . . . . .	12
3	Comparison of Silikal® Versions . . . . .	15
4	Summary of Repair Tasks . . . . .	72
5	Summary of Equipment Utilization. . . . .	73
6	Field Testing Results . . . . .	75
7	F-4 Loadcart Testing Results. . . . .	76
8	Surface Roughness Measurements. . . . .	90

## SECTION I

### INTRODUCTION

#### 1. BACKGROUND

High performance military aircraft depend on a high quality surface for launch and recovery operations. This dependency makes the airfield a prime target for enemy attack. Consequently, the rapid repair of weapon-damaged runways is a vital capability following an airbase attack. This urgent requirement has led to the Rapid Runway Repair (RRR) research and development program at the Air Force Engineering and Services Center (AFESC).

The Small Crater Expedient Repair Test concludes a four-year in-house effort to identify and test commercially available materials for the flush repair of small craters (less than 20 feet in diameter) and scabs (damage that does not penetrate to the subgrade) in runways. The equipment available to effect these repairs was limited to that currently in the Air Force inventory. The limitations on materials and equipment were necessary due to an urgent requirement to respond in the near term to deficiencies in the current bomb damage repair procedure as described in AFR 93-2, Base Recovery Planning (Reference 1).

These deficiencies include a lack of flexibility to respond to a large number of multi-sized craters and concern over the roughness of the 1-1/2 inch bump caused by the AM-2 aluminum matting used in the AFR 93-2 procedure (Reference 2).

A series of five technical reports document the in-house work leading to the Small Crater Test:

a. CEEDO-TR-78-44, Laboratory Evaluation of Expedient Pavement Repair Materials (Reference 3) identified high alumina cement, magnesium phosphate cement, three commercial asphalt products, and unsurfaced compacted aggregate as promising small crater repair materials.

b. ESL-TR-79-07, Summary Report on Amalgapave Testing, January 1976-August 1978 (Reference 4) reported the Air Force knowledge, testing, and experience with Amalgapave as of August 1978. This technical report was intended as an interim guide to the field user on the use of Amalgapave, a proprietary cold mix asphalt used for the repair of scabs.

c. ESL-TR-79-01, Interim Field Procedure for Bomb Damage Repair (Reference 5) described a procedure for performing repairs of large and small bomb craters using crushed stone as the repair material. The report also describes a rapid scab repair technique using a proprietary polymer-concrete product. This report, like the Amalgapave report, was intended to transfer current

technology to the field in advance of final development and validation in order to fill critical gaps in the Air Force's Rapid Runway Repair capability.

d. ESL-TR-79-08 and ESL-TR-80-51 are both entitled Field Test of Expedient Pavement Repairs and report items 1-15 and 16-35, respectively, of tests performed at Tyndall AFB's Small Crater Test Facility (References 6 and 7). These tests subjected candidate repair materials to F-4 loadcart traffic. As a result of this testing program, the fast-setting cements were eliminated due to handling difficulties, and cold-mixed asphalt products were eliminated due to insufficient stability. Crushed limestone was capable of carrying the F-4 loads if sufficiently compacted, but the compaction time was too long with current USAF equipment. However, due to the good performance of crushed limestone as a repair material, the inventory equipment limitation was slightly modified to permit testing of heavy vibratory rollers for compaction of crushed limestone. Subsequent testing demonstrated the feasibility of compacting crushed limestone from the surface only to support F-4 wheelloads. Polymer-concrete was added later in the effort as a candidate material since some off-the-shelf products had become available and appeared promising. Testing at Tyndall showed polymer-concrete was capable of supporting F-4 traffic, but existing USAF equipment was not capable of handling the polymer concrete in bulk. As a result, an individual bag mixing system was adopted using Silikal®, a proprietary methyl methacrylate-based polymer-mortar manufactured by Karl Ullrich and Company of Germany and their licensees.

## 2. TEST OBJECTIVE

The objective of the Small Crater Expedient Repair Test was to field test repair techniques and determine repair times for the expedient repair of small craters using materials and techniques developed during testing at the Small Crater Test Facility. The repairs were evaluated for F-4 aircraft traffic.

## 3. APPROACH

From 25 July to 7 August 1979, six small craters were explosively formed and repaired: four using the compacted crushed limestone repair and two using the polymer-concrete repair. The equipment package and repair crew were selected to represent one-third of a typical BDR repair kit as specified in AFR 93-2, minus the equipment and manpower not required for the two repair techniques. Craters 1 and 2 were practice repairs for the crushed limestone and polymer-concrete techniques, respectively. Craters 3 and 4 were timed repairs for each technique. Craters 5 and 6 were timed simultaneous repairs using the crushed limestone technique.

Following each repair, simulated F-4 aircraft traffic was applied using the loadcart shown in Figure 1. This loadcart

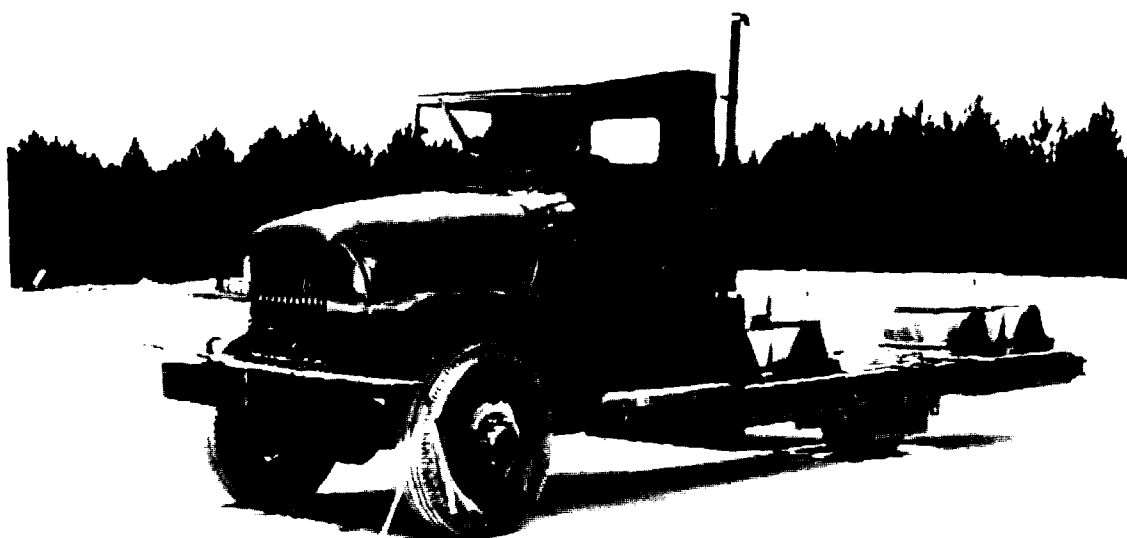


Figure 1. F-4 Loadcart

applied a 27,000 pound main gear load at a tire pressure of 265 psi. Traffic was applied in an approximated normal traffic distribution over a 10-foot width as shown in Figure 2. The loadcart was driven forward and backward in the same wheel path prior to moving to the next lane. A total of 96 passes of the main gear load were placed on the test item to obtain 10 coverages of the traffic in the center six lanes, eight coverages in the four lanes adjacent to the center lanes, and two coverages in the two outside lanes. This traffic distribution is representative of actual aircraft traffic distribution on a runway and avoids introducing a sharp discontinuity between trafficked and untrafficked areas (Reference 8).

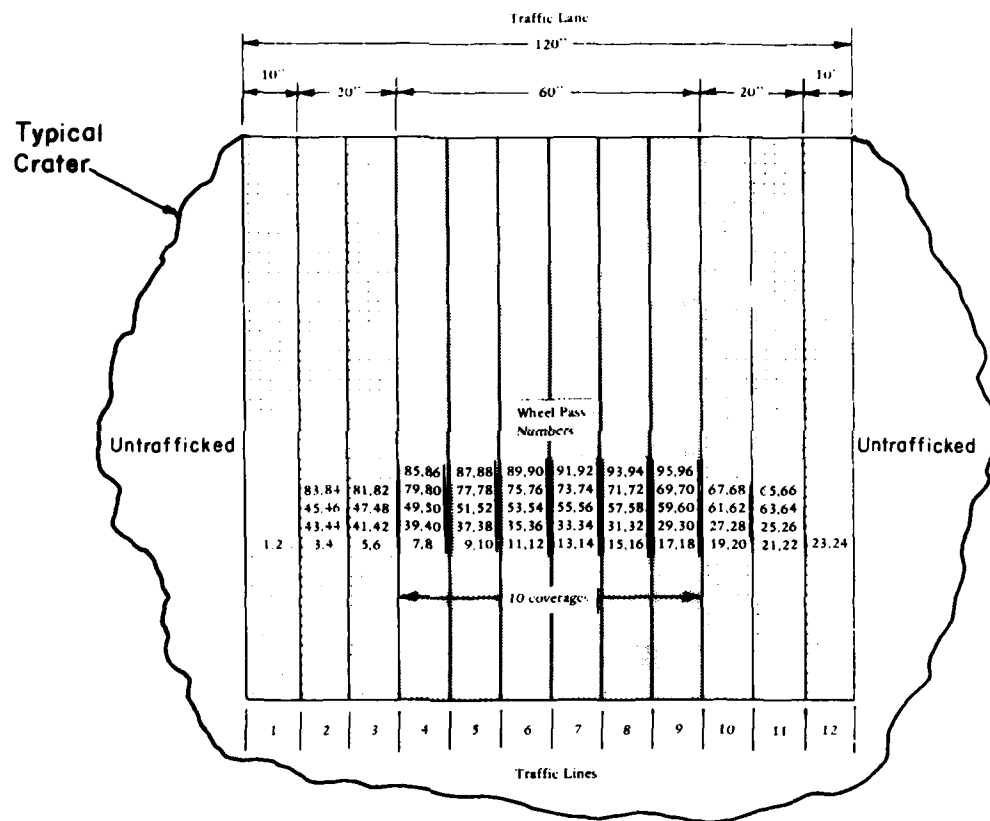


Figure 2. Traffic Pattern for F-4 Loadcart

## SECTION II

### DESCRIPTION OF TESTS

#### 1. TEST SITE

The test site was located in a remote, little used area in the southeast portion of Tyndall Air Force Base. This site had previously been used for explosive testing of bomb damage repair procedures in 1973 and 1974. At this site a test pad was reconstructed which would simulate a typical USAFE runway.

The entire test pad has a 12-inch-thick, well-graded base course of crushed limestone, and a 12-inch-thick concrete pavement. Additionally, the east half of the test pad had a four-inch asphaltic concrete overlay.

Six crater locations were selected on the pad, as shown in Figure 3. Craters 1 through 4 were located in the center of the 15 by 15-foot slabs, Crater 5 at the joint between two slabs, and Crater 6 at the corner of four slabs. At each crater location was a clay core subgrade, as shown in Figure 4.

A clay subgrade was used in the Small Crater Tests in order to simulate a worst case, low strength subgrade. The clay subgrade was composed of a local clay obtained near Wewahitchka, Florida. The moisture content of the clay at Craters 1, 4, 5, and 6 was approximately 30 percent, with a California Bearing Ratio (CBR) of 4 and a dry density of 90 pounds per cubic foot (pcf). The clay at Craters 2 and 3 had a moisture content of approximately 15.5 percent, a CBR of 30, and a dry density of 105 pcf. The clay also had the following characteristics (Reference 9):

Gradation	See Figure 5
Specific Gravity	2.61
Liquid Limit	65%
Plasticity Index	41%
Unified Soil Classification	CH
Maximum Dry Density (Modified AASHO)	113 pcf
Optimum Moisture Content	14.5%

#### 2. CRATER INFORMATION

The craters were all formed with 25 pounds of C-4 explosive, with the exception of Crater 5. This crater used 18.75 pounds of C-4 plus four pounds of TNT due to a shortage of C-4 on hand. All explosives had a depth of burst of approximately five feet, except for Crater 1 whose depth of burst was 4-1/2 feet. The crater dimensions are given in Table 1 for both the apparent crater and for the actual repaired crater. All of the repaired craters

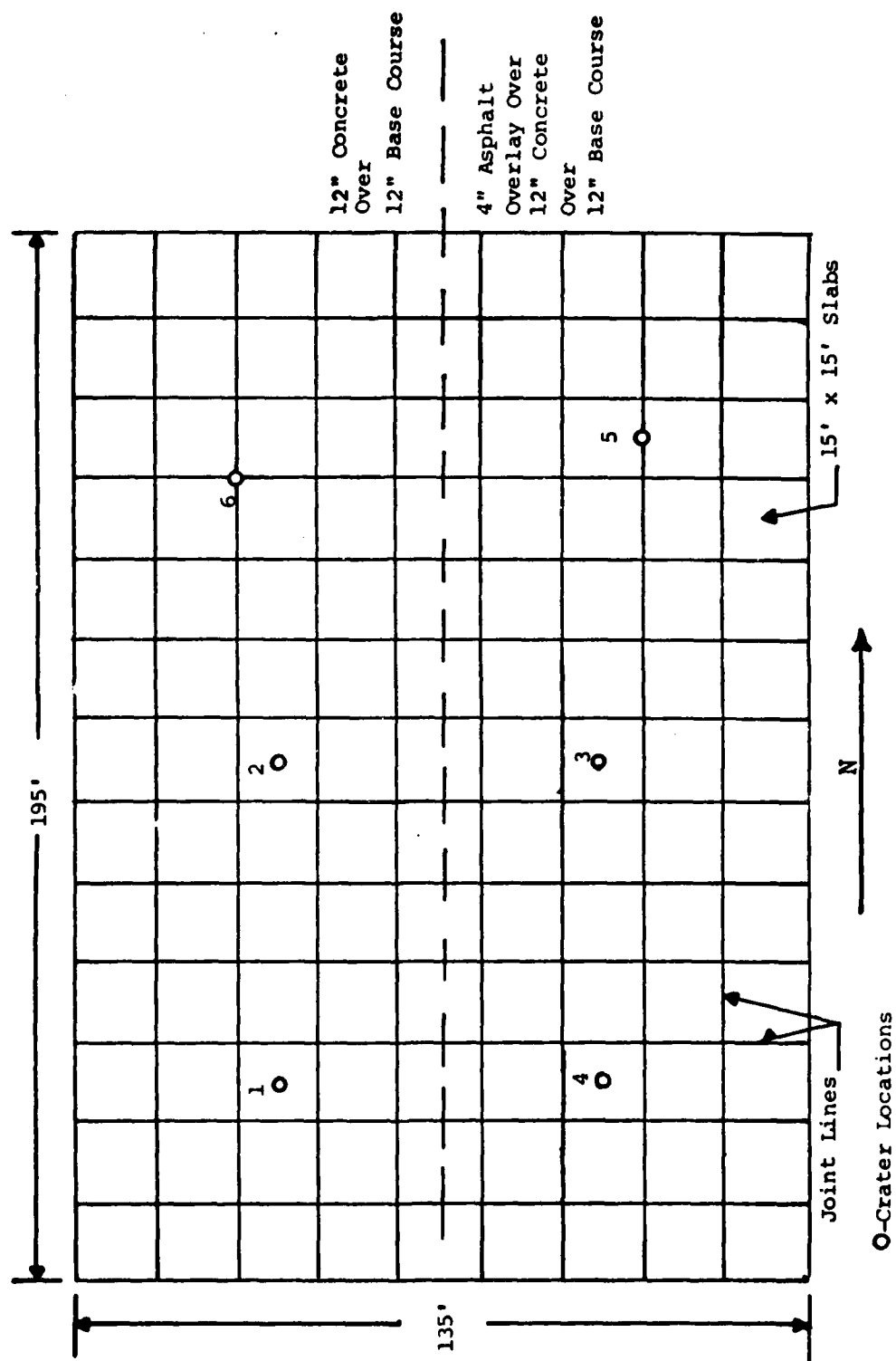


Figure 3. Plan View of Test Site

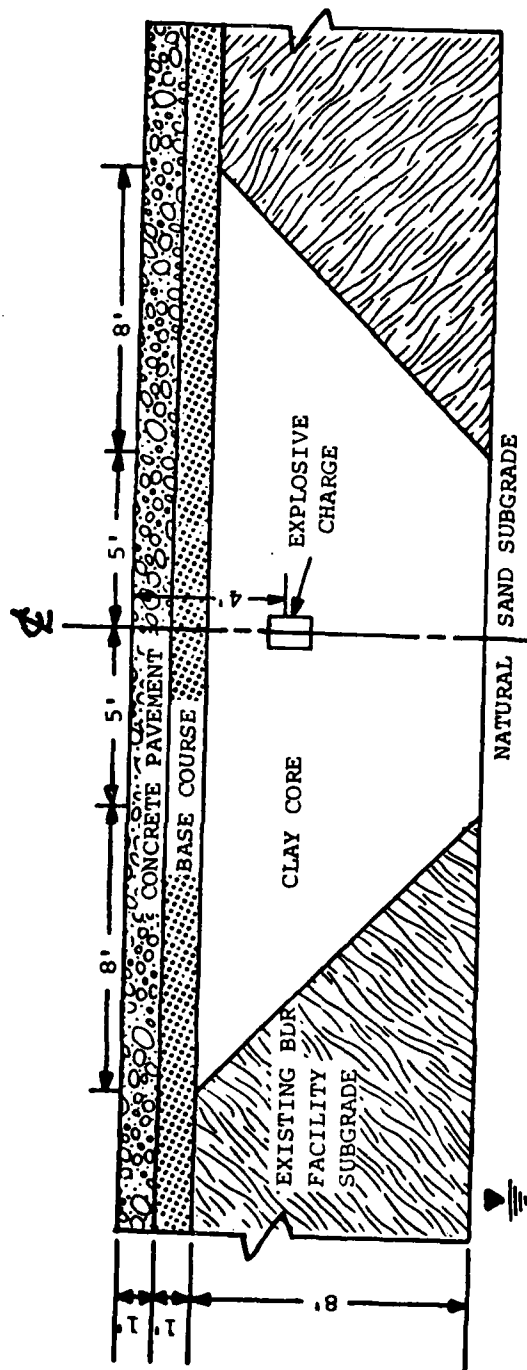


Figure 4. Cross Section of Clay Core

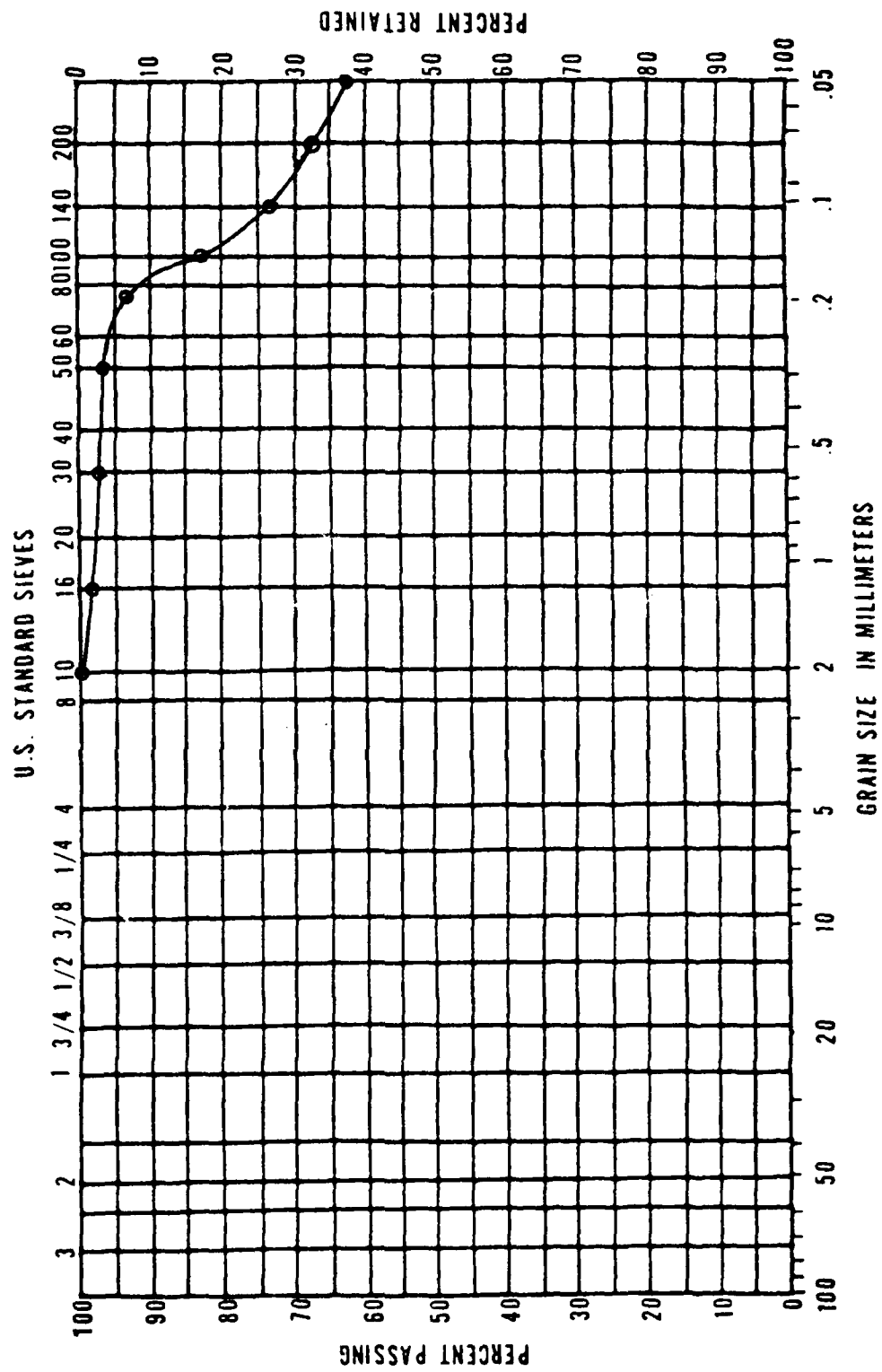


Figure 5. Gradation of Wewahitchka Clay

TABLE 1. CRATER INFORMATION

Crater Number	Explosive	Depth of Burst (feet)	Apparent Crater				Repair Crater			
			Depth (feet)	Diameter (feet)	Area (feet <sup>2</sup> )	Volume (feet <sup>3</sup> )	Depth (feet)	Diameter (feet)	Area (feet <sup>2</sup> )	Volume (feet <sup>3</sup> )
1	25 lb C-4	4.5	5.0	17	227	598	5.0	18.4	266	1084
2	25 lb C-4	5	1.0	18	254	168	1.0	22.0	380	368
3	25 lb C-4	5	1.3	15	177	129	2.5	23.7	441	1020
4	25 lb C-4	5	6.2	15	177	664	5.4	24.2	460	2102
5	18 3/4 lb C-4 4 lb TNT	5	3.0	17	227	500	2.6	23.9	449	1076
6	25 lb C-4	5	4.6	17	227	589	4.3	30.6*	936	2580

\*Square Crater

except Crater 1 exceeded the size of a small crater by definition (repair diameter less than 20 feet). Nevertheless, with the exception of Crater 6, the sizes were small enough to be typical of small craters.

### 3. EQUIPMENT AND PERSONNEL

The equipment used in the Small Crater Test was selected to represent the equipment available in a modified AFR 93-2 rapid runway repair kit. Table 2 shows the AFR 93-2 heavy equipment allocations based on three large craters, the allocations as modified for one large crater, and the actual equipment used for the Small Crater Test. AFESC/RDCT supplied all equipment used. Specifications for the RayGo 410 vibratory roller, the International Harvester TD-20 tracked dozer, and the Allis Chalmers 745 wheel loader are given in Appendix A.

The size and power of some of the equipment available for the Small Crater Test differed from that normally found in a typical AFR 93-2 RRR kit. The 5-ton dump trucks specified in AFR 93-2 were simulated with 10-ton dump trucks which were only half-filled with approximately five cubic yards per load. Only three dump trucks were used in the Small Crater Test due to the relatively small quantity of select fill that was required to be handled. The TD-20 dozer was not operating at its peak power due to age (1966 vintage). Lack of power proved to be a problem in removing upheaved pavement, as discussed later in Section III.

The repair team used in the Small Crater Test was comprised of one lieutenant (Repair Team OIC) from AFESC and twelve enlisted men from 823d CES (RED HORSE) at Hurlburt Field, Florida. The enlisted troops ranged in rank from Airman (E-2) to Technical Sergeant (E-6) (Repair Team NCOIC), with from nine months to 13 years experience as equipment operators. For Crater 4, the above repair team was augmented with two men from AFESC during the placement of the polymer-concrete in an effort to increase placement speed and efficiency.

### 4. REPAIR MATERIALS

The crushed limestone repair was tested on Craters 1, 3, 5, and 6. This repair employs a minimum of 24 inches of unsurfaced crushed limestone with the following characteristics (Reference 9):

Gradation	See Figure 6
Specific Gravity	2.76
Liquid Limit	Non-plastic
Plasticity Index	Non-Plastic
Unified Soil Classification	GW-GM
Maximum Dry Density (Modified AASHO)	145.6 pcf
Optimum Moisture Content	5.1%

TABLE 2. HEAVY EQUIPMENT ALLOCATIONS

AFR 93-2

<u>Nomenclature</u>	<u>3 Craters</u>	<u>1 Crater</u>	<u>Small Crater Test</u>
Truck, Pickup, 1/2-Ton	2	1	1
Truck, Tractor, 10 Ton	3	1	1
Truck, Dump, 5 Ton	15	5	3 (10-Ton)
Trailer, Semi, 22 Ton	3	1	1
Tractor, Full track	3	1	1
Grader	3	1	1
Tractor, IW55	5	2	1
Loader, Scoop-tired, 2.5 cy	7	3	3
Roller, Towed, Vibratory	3	1	0
Roller, Self-propelled, Vibratory	0	0	2
Sweeper, Towed, Rotary	2	1	1
Sweeper, Vacuum, Self-propelled	2	1	0

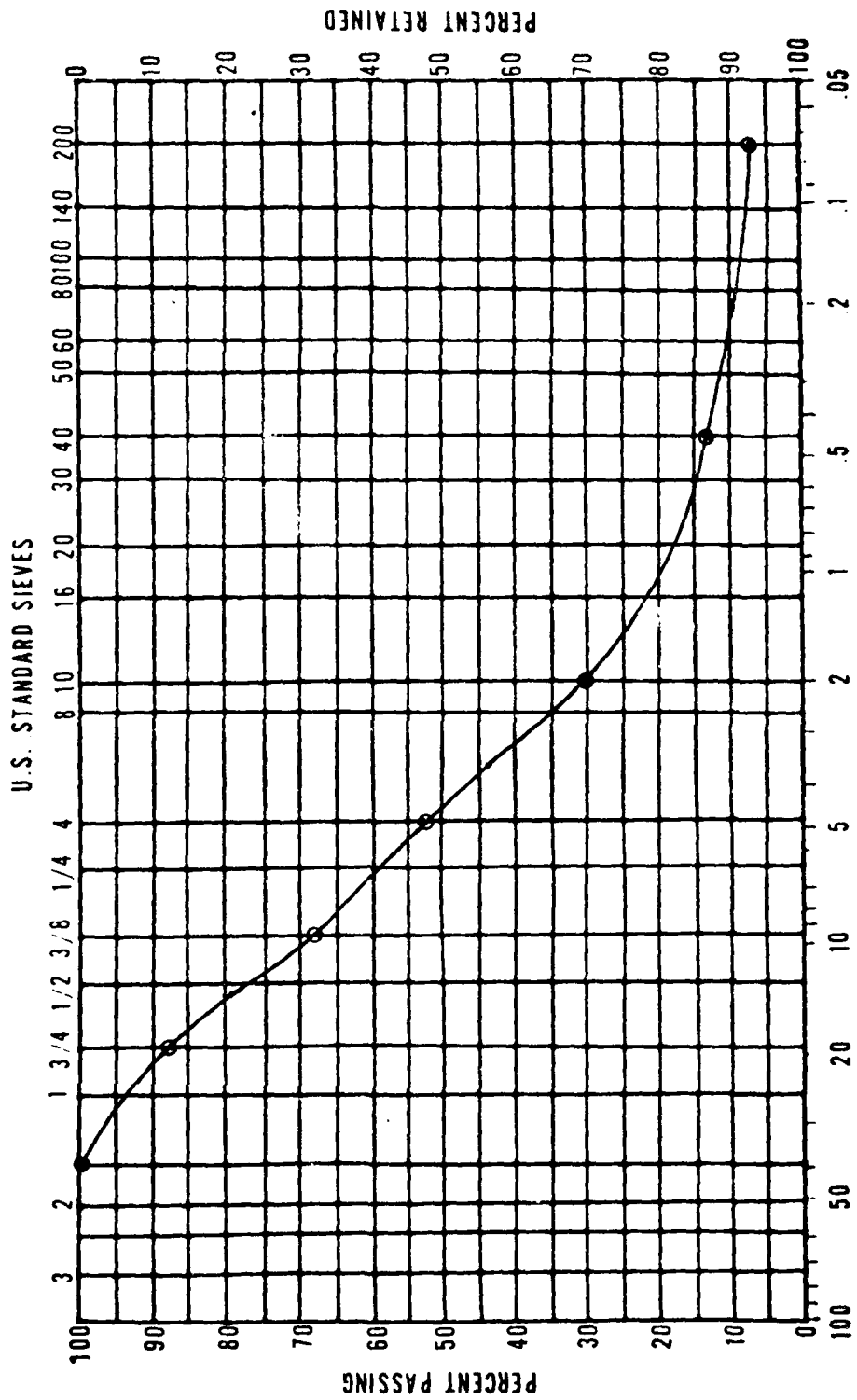


Figure 6. Gradation of 1 1/2 inch Crushed Limestone

The polymer-concrete repair was tested on Craters 2 and 4 using Silikal®, a proprietary product of Karl Ullrich and Company of Germany. This company has several licensees who produce this material in the United States and Germany.

Silikal® is a methacrylate-based polymer mortar. It is made by mixing dry sand and powdered polymer with liquid hardener. There are several versions of Silikal® available. The commercially-available versions are Silikal® R-7 and Silikal® R-17. Silikal® R7/Bw is a special version made only for the German armed forces for bomb damage scab repair. The Small Crater Test employed a special production which was a 50/50 mix of Silikal® R-7 and R-17, based on the manufacturer's recommendation to reduce shrinkage. The Silikal® R-7/R-17 was packaged in individual 30-pound bags of the powder and half-gallon containers of the liquid, producing 0.27 cubic feet of mortar per bag. Table 3 compares the various Silikal® versions.

## 5. CRUSHED LIMESTONE REPAIR PROCEDURES

This subsection discusses the procedures used in the repair of small craters using crushed limestone. Figure 7 is a diagram showing the sequence of tasks involved in this repair.

### a. Crater Preparation

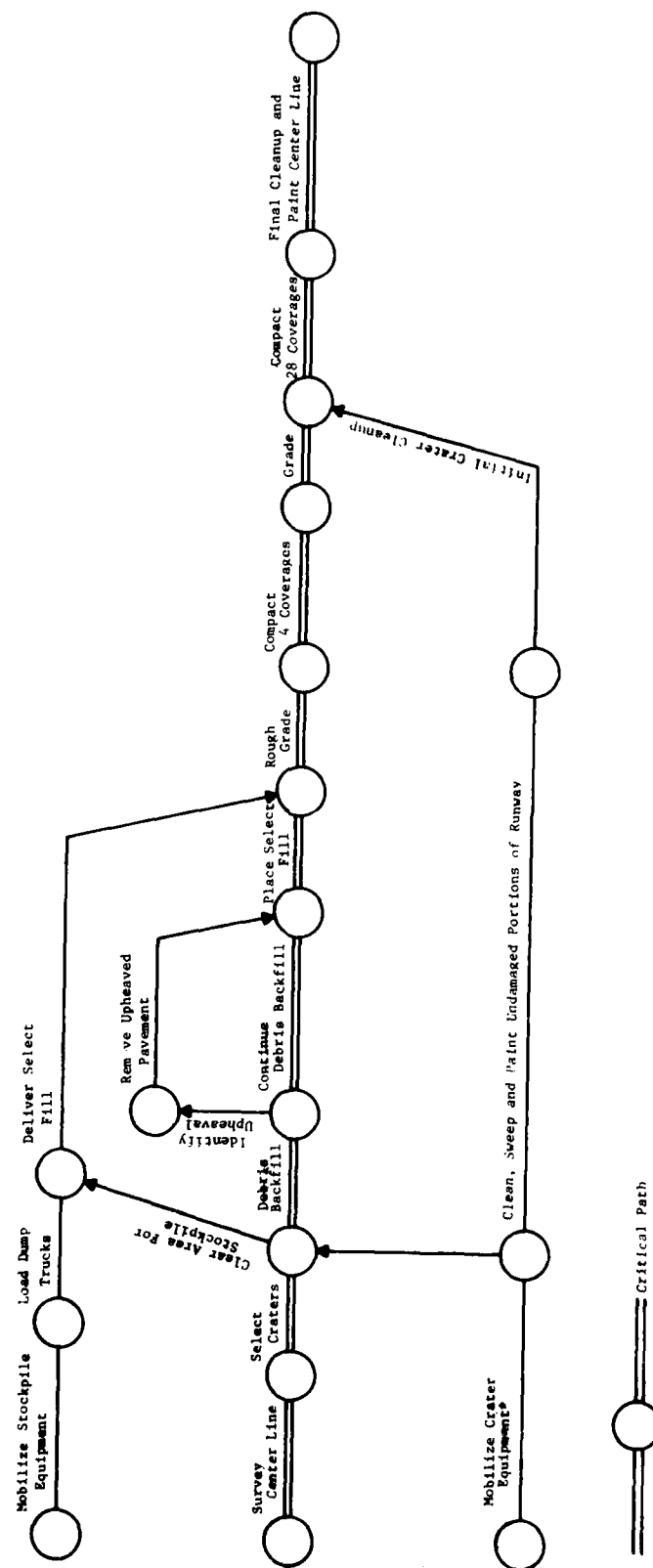
The repair of the runway starts in the same manner as the procedure described in AFR 93-2. The first task on the critical path for minimum repair time is to survey and establish the runway centerline and select the craters to be repaired. Concurrently, the repair team and equipment are mobilized and delivered to the repair site and the crushed limestone stockpile, as appropriate. For the Small Crater Test equipment mobilization lies on the critical path since the tasks of surveying and establishing the runway centerline and selecting craters were not tested. The next critical path task is to push debris into the crater up to 24 inches below the pavement surface, and compact the debris using the dozer and the loader. At the same time an area near the crater must be cleared to stockpile the crushed limestone (select fill). During the debris backfilling, the grader and sweepers can begin clearing the undamaged portions of the runway, and the stockpile loader and dump trucks can begin delivery of the crushed limestone to the cleared crater stockpile area.

Once the crater is filled to permit operations inside the crater, the dozer, if possible, should enter the crater to compact the debris and to remove the upheaved pavement. Only upheaved pavement with a change in slope in excess of 1.5 percent required removal. The 1.5 percent requirement represents a compromise criteria used only for the Small Crater Test. It was based on actual aircraft testing which shows the 3-percent change

TABLE 3. COMPARISON OF SILIKAL® VERSIONS

	R-7	R-17	R-7/R-17	R-7/Bw
Description	Commercially available for concrete overlays	Commercially available for concrete patching	Special production for testing. 50/50 mixture of R7/R17	Commercially produced for the German Military. Derivative of R-7
Primary Advantages	high strength	low shrinkage	compromise between strength and shrinkage	long shelf life rapid cure in low temperature
Physical Properties*				
Compressive strength	11,000 psi	8,000 psi	9,500 psi	11,000 psi
Modulus of Elasticity	$2.5 \times 10^6$ psi	$1.0 \times 10^6$ psi	$1.7 \times 10^6$ psi	$2.5 \times 10^6$ psi
Thermal Expansion	$2.5 \times 10^{-5}$ /°C	$3.3 \times 10^{-5}$ /°C	$2.9 \times 10^{-5}$ /°C	$2.5 \times 10^{-5}$ /°C
Shrinkage by Volume	0.1 percent	0.04 percent	0.07 percent	0.1 percent
Shelf Life	18 months	18 months	18 months	5 years
Temperature Range	14°F to 100°F	14°F to 100°F	14°F to 100°F	-10°F to 100°F
Cure Time @ 72°F	30 minutes	30 minutes	30 minutes	17 minutes
Cure Time @ 25°F	3-4 hours	3-4 hours	3-4 hours	20 minutes (with accelerator)

\*Note: The given values are taken from manufacturers data which in many cases use German Standard tests rather than U.S. The values should be used to compare one version to another. These values should not be used for specifications, calculations, or comparisons to other materials.



\*Note: Mobilize crater equipment is on the critical path for Explosive Crater Test.

Figure 7. Crushed Limestone Repair Sequence of Tasks

in slope of an AM-2 mat ramp section to be potentially damaging to the aircraft. If the crater is too small to permit the dozer to effectively use its blade for removal of upheaved concrete, the repair team will have to revert to alternate removal methods (i.e., the loader bucket, the dozer's ripper tooth, the loader outfitted with the fork attachment, or the jackhammer as a last resort). If pavement upheaval is significant, its removal may be on the critical path.

b. Select Fill Placement

After the crater preparation is complete, placement of the select fill (crushed limestone) begins. The loader should push the limestone from the crater stockpile into the crater. All select fill delivered after the crater is prepared should be dumped directly into the crater by the dump trucks. The crater should be overfilled approximately six inches to allow for compaction, as shown in Figure 8. At this point in the repair it is not critical that the crushed limestone be perfectly level; hence, the loader is satisfactory for leveling the surface (Figure 9).

c. Compaction of the Crushed Limestone

Once the crater has been filled with crushed limestone, compaction using the self-propelled vibratory rollers can begin. The frequency of the vibration should be as high as possible unless local experience indicates a better frequency for local materials (Reference 10). The roller should traffic the repair in the direction requiring the least number of lanes, allowing six to twelve inches of overlap between lanes. Initially the roller should compact each lane four times (twice back and forth) and then move on to the next adjacent lane, until the entire repair has four passes of the vibratory roller applied.

After the four passes of the roller have been applied to each lane, the patch should be releveled with the grader to approximately 1-1/2 inches above the surrounding pavement (Figure 10). An experienced grader operator can do this in a single pass per lane with only a minimum amount of shovel work required.

The next step in the repair is to continue applying compaction to the crushed limestone. The vibratory roller should apply a total of 28 more passes, in multiples of four passes, to each lane of the repair. This makes a total of 32 coverages over the entire repair. This task lies on the critical path for minimum repair time, and two rollers should be used if available. For the Small Crater Test two rollers were made available to the repair team for the simultaneous repair of Craters 5 and 6 only.

During and after compaction of the crushed limestone, the repair must be inspected for surface roughness. Currently, testing is in progress to determine acceptable surface roughness

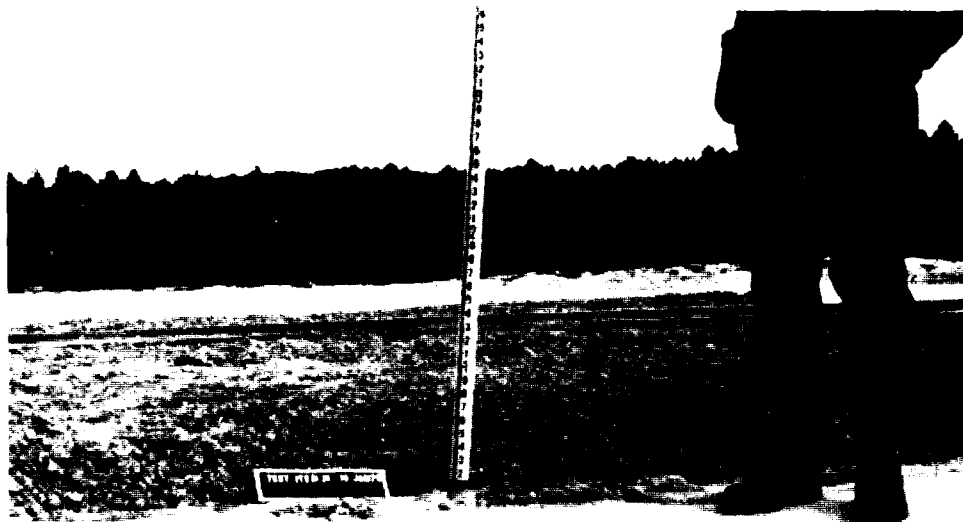


Figure 8. Crater Overfilled 6 Inches With Crushed Limestone



Figure 9. Leveling Crushed Limestone With the Loader



Figure 10. Leveling Crushed Limestone With the Grader

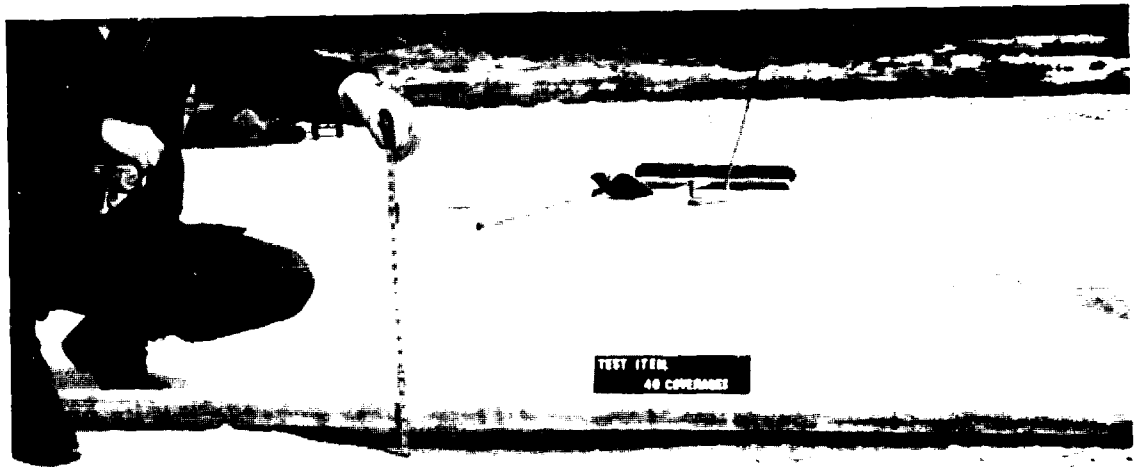


Figure 11. Consolidation of Crushed Limestone at Edge of Concrete

criteria. For the Small Crater Test, the following recommendations were used (Reference 5):

The crushed stone should not exceed one inch in height above the adjacent concrete or extend below the adjacent concrete by two inches. Careful attention must also be given to the joint between the crushed stone and the existing concrete such that the crushed stone never falls one-half inch below the level of the concrete creating a sharp bump which might damage the aircraft (Figure 11). If the crushed stone compacts below one-half inch at the concrete joint, additional material should be added and compacted.

#### d. Foreign Object Damage (FOD) Cover

After compaction of the crushed limestone has been completed, the patch can be covered with a FOD cover. The requirement for such a cover has not been firmly established, but research is currently underway to determine if a FOD cover is required, and if so, what type of cover would be most suitable.

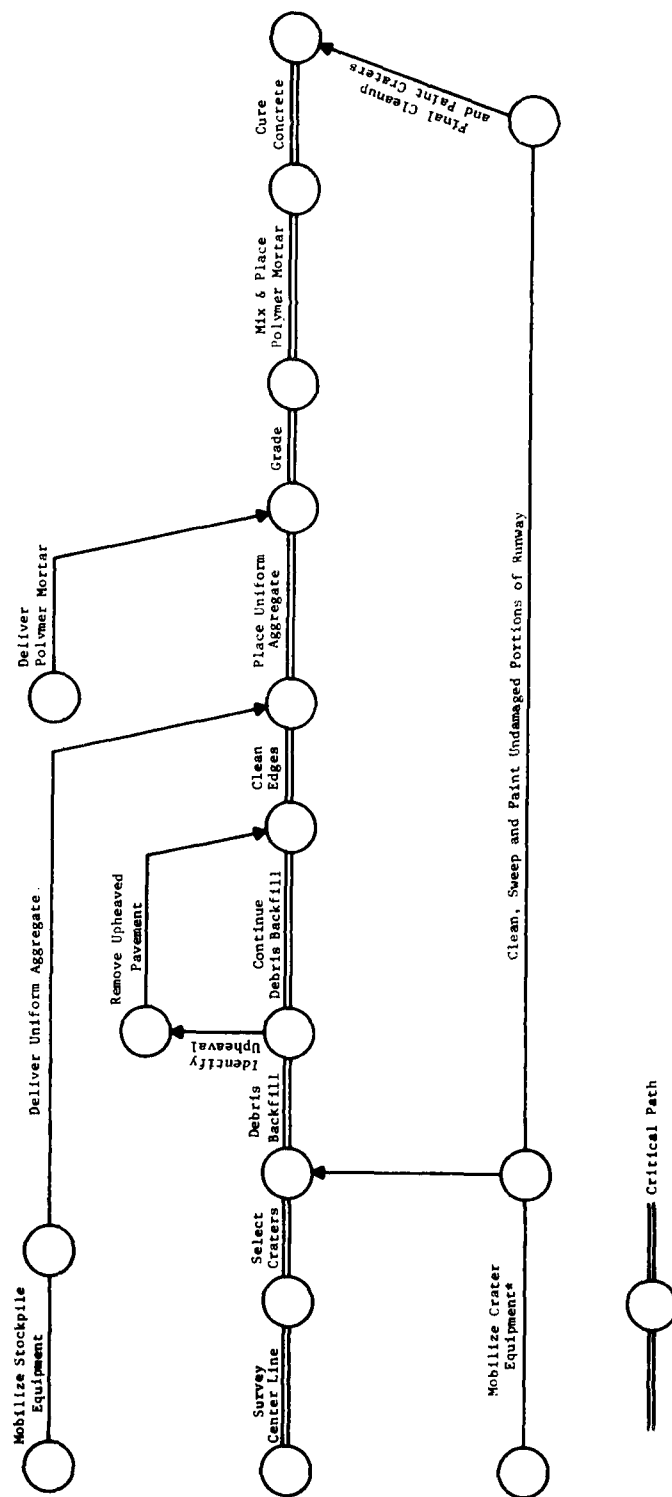
For the Small Crater Test, only Crater 1 was covered with a FOD cover. Based on early testing by AFESC, a T-17 membrane FOD cover was placed over the repair and attached to the surrounding concrete using steel strips and ram-set nails. This was a minor portion of the Small Crater Test designed to identify any major problems in handling a FOD cover. Once the optimum FOD cover is selected, more extensive field testing will be undertaken.

### 6. POLYMER-CONCRETE REPAIR PROCEDURES

This section discusses the procedures used in the repair of small craters using polymer-concrete. Figure 12 is a diagram showing the sequence of tasks involved in this repair.

#### a. Crater Preparation

Crater preparation for the polymer-concrete repair closely corresponds to the preparation required for the crushed limestone repair. The major difference is that the debris backfill can be brought up to eight inches below the pavement surface instead of the 24 inches required in the crushed limestone repair. Also the clearing of a stockpile area near the crater may not be necessary due to the relatively small amount of fill required. Another difference from the crushed limestone repair is the polymer-concrete repair requires that loose debris and unsound pavement be removed to the maximum extent practical from the surrounding pavement edges in order to insure a good bond between the polymer-concrete and the existing pavement.



\*Note: Mobilize crater equipment is on the critical path for Explosive Crater Test.

Figure 12. Polymer-Concrete Repair Sequence of Tasks

While the debris backfill and upheaval removal are underway, delivery of the select fill (two-inch uniform aggregate) and the polymer-mortar should begin. Cleanup of the undamaged portions of the runway should also be started.

b. Placement of Uniform Aggregate

After the crater has been prepared, the two-inch uniform aggregate should be placed in the crater and graded level with the surrounding pavement.

c. Placement of the Polymer-Mortar

The next step in the repair is the placing of the polymer-mortar. The polymer-mortar should be mixed according to the manufacturer's instructions and immediately poured over the leveled uniform aggregate. Based on testing at AFESC, the mortar will percolate through the uniform aggregate to a depth of approximately six to eight inches. The polymer-mortar should then be screeded level with the surrounding pavement. The mortar has a working life of only 10 to 15 minutes, so care must be taken not to allow the pouring operation to get too far ahead of the screeding operation.

After the repair has been completely screeded, the polymer-concrete must be allowed to cure 45 to 90 minutes, depending on ambient temperatures. During this time, final cleanup and painting of the centerline stripe can be accomplished. After the cure period the repair can be trafficked with aircraft.

Polymer-concrete must be placed under dry conditions to insure a good bond to the remaining pavement and to the aggregate. In case of wet weather, the aggregate should be protected from getting wet if possible. Also, some type of shelter should be placed over the crater during the repair operation to keep the repair area as dry as possible. A method for drying the pavement edges is also required. Hot or cold-air dryers or infrared heaters can be used. For the Small Crater Test a large tarp stretched between two dump trucks was prepared for use as a crater shelter. Also, two Herman-Nelson hot-air dryers were available to dry the pavement. However, no wet weather techniques were used.

## 7. REPAIR EVALUATION PROCEDURES

This subsection documents the test monitoring and data collection procedures used in the Small Crater Test. Also included is a discussion of the failure criteria used to evaluate the finished repairs.

#### a. Photographic Coverage

Various forms of photographic coverage were used to gather data throughout the test. Time-lapse motion picture coverage of the repair was made for time and motion studies. Video tape coverage was also made to allow real time analysis of the repair procedures and to debrief the RED HORSE repair team. Finally, 35mm slides were taken of the repairs for use in analysis, technical reports, and briefings.

The time-lapse and video tape efforts were not as successful as had been hoped. Malfunctions plagued both the time-lapse and video tape equipment, and inappropriate shots and camera angles diminished the usefulness of the film footage. The real time video tape did prove useful in debriefing the repair teams. Nevertheless, photographic coverage combined with other data provided an accurate record of events taking place during the tests.

#### b. Visual Observations

A team of five observers were selected to monitor the Small Crater Test as follows:

Observer No. 1 was assigned to the stockpile area, and Observers No. 2 and 3 were assigned to the test site. These observers were responsible for recording the various functions of all the equipment working at their respective locations. Each observer was assigned specific equipment to observe prior to the start of the repair and recorded his information on Time Sequence Logs as shown in Figure 13.

Observer No. 4 was assigned to the test site and was responsible for recording the start and finish times of the various tasks associated with each repair. He recorded his observations on the form shown in Figure 14.

Observer No. 5 was assigned to the test site and was responsible for recording general information on the repairs. He recorded his observations on a hand-held tape recorder which was later transcribed into manuscript.

#### c. Quality and Material Testing

Several field tests were performed during the Small Crater Test in order to evaluate the quality of the repairs. The subgrade tests included California Bearing Ratio (CBR) determinations, Plate Bearing Tests to determine the modulus of subgrade reaction (k) (Reference 9), and soil moisture and density tests. Soil moisture and density testing of the crushed limestone fill was also performed. The moisture and density

## TIME SEQUENCE LOG

ITEM # \_\_\_\_\_ 19 \_\_\_\_\_

**OBSERVER** \_\_\_\_\_ **POSITION** \_\_\_\_\_

[illegible]

**Figure 13. Time Sequence Log Form**

# SMALL CRATER TEST TASK START & FINISH TIMES

ITEM # \_\_\_\_\_ 19 \_\_\_\_\_ NAME \_\_\_\_\_

CRUSHED STONE TECHNIQUE: TASKS	START	FINISH	COMMENTS
START			
SURVEY DAMAGE			
DELIVER EQUIP TO SITE			
CLEAR AREA FOR FILL STOCKPILE			
PUSH DEBRIS IN CRATER & COMPACT			
CLEAN AND SWEEP			
DELIVER SELECT FILL			
IDENTIFY LIP TO BE REMOVED			
REMOVE UPHEAVAL			
PLACE SELECT FILL			
CAMPACT WITH 4 COVERAGES			
GRADE			
COMPACT WITH 28 COVERAGES			
CUT T-17 MEMBRANE			
DRAG T-17 MEMBRANE IN PLACE			
ANCHOR T-17 MEMBRANE			
FINISH			

POLYMER-CONCRETE TECHNIQUE: TASKS	START	FINISH	COMMENTS
START			
SURVEY DAMAGE			
DELIVER EQUIP TO SITE			
PUSH DEBRIS IN CRATER & COMPACT			
CLEAN AND SWEEP			
IDENTIFY LIP TO BE REMOVED			
REMOVE UPHEAVAL			
DELIVER UNIFORM AGGREGATE			
PLACE UNIFORM AGGREGATE			
GRADE			
DELIVER POLYMER-CONCRETE			
MIX & PLACE POLYMER-CONCRETE			
SCREED			
FINISH			

Figure 14. Task Start and Finish Times Form

measurements were made with the Troxler 3411B nuclear moisture-density gauge shown in Figure 15. Past research has demonstrated that the accuracy to be expected from nuclear gauges is at least as good as conventional field methods, such as the sand cone or water balloon density methods (Reference 11). The nuclear moisture content readings were adjusted using oven-dried moisture content samples (Reference 9), and dry densities were calculated using the corrected moisture contents.

In addition to the above tests, elevation profiles were taken of each crater prior to the explosive detonation, after the detonation, after placement of the debris backfill (Craters 1 and 2 only), and before, during, and after F-4 loadcart trafficking. Profile data was recorded on special forms shown in Figure 16. Figure 17 depicts how the profile data was collected.

#### d. Failure Criteria

The failure criteria for expedient repairs is very difficult to establish. Repairs which would be termed failed under conventional circumstances may still be functional for emergency operations. Improved criteria need to be established, but the criteria described in this subsection provide a reference point to previous testing although they haven't been tested with aircraft. For the Small Crater Test, a three-inch rut determined failure for the crushed limestone repair. For the polymer-concrete repair, a loss of structural integrity of the concrete (such as "punching through" the structural cap) constituted failure.

At the time of this testing the length of time a repair must last had not been firmly established by the Air Force. Earlier testing has used criteria ranging from 16 to 100 passes as the minimum capacity required, but higher capacities are believed to be needed. For the purposes of this field test, 12 coverages (115 passes) and 150 coverages (1440 passes) were arbitrarily established as the minimum acceptable and the maximum required repair capacity for an expedient repair, respectively.

Overall settlement of the repair was not a basis for failure as long as the minimum acceptable repair capacity of 12 coverages had been attained. When overall settlement is deemed hazardous to aircraft operation, additional crushed stone or polymer-concrete can be added as required.



Figure 15. Trex ... i to c ... sic ... nge

NUCLEAR MOISTURE & DENSITY LOG

ITEM # \_\_\_\_\_ 19 \_\_\_\_\_

[illegible]

28

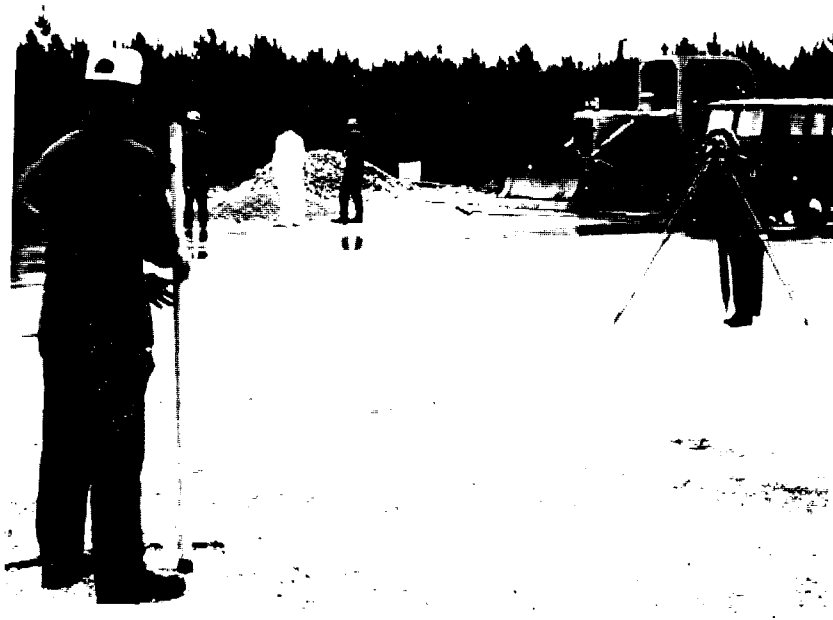


Figure 17. Profiling the Craters

### SECTION III

#### ANALYSIS OF REPAIR PROCEDURES

##### 1. CRUSHED LIMESTONE REPAIR

###### a. Crater 1 - Procedural Practice Repair

The first test performed in the Small Crater Test was a practice repair of the crushed limestone method. The repair team was instructed in advance on repair procedures and told to emphasize repair quality over repair time. Figure 18 shows the rather large clay chunks which were a problem to the repair team for Crater 1, as discussed later in this subsection. Figure 19 is a work flow diagram showing the sequence and duration of repair tasks for Crater 1. This diagram and all of the subsequent time-data charts represent a compilation of all test data required.

As can be seen in Figure 19, the first critical task is the mobilization of equipment to work at the crater site (principally the loader). The repair equipment was marshalled and ready in an area 0.8 mile south of the test site; hence, the two minutes required for mobilization represent the time from notification of start of test to actual arrival on site of the repair team OIC, NCOIC, and the wheel loader. The crushed limestone was stockpiled 0.8 mile north of the test site, requiring the dump trucks and stockpile loader to travel approximately 1.6 miles during mobilization.

Upon arrival at the crater site, the loader immediately began to push the debris either into the crater or to the side of the runway. At the same time the grader operator began clearing an area for stockpiling the initial deliveries of crushed limestone. The actual utilization of equipment is graphically shown in Figure 20. It should be noted that the dozer was not used at all in this repair (although it was tested for its pavement removal capability as discussed later). The repair team OIC said he felt the dozer was not appropriate for a small crater due to its large size and limited maneuverability.

When the repair team began work, it quickly became obvious that there was a general lack of experience in crater repair despite some prior exposure and practice with the current AFR 93-2 bomb damage repair procedures. During the debris backfill task, the loader operator wasted a lot of motion by haphazardly clearing the debris around the crater rather than working in an orderly fashion all the way around the crater perimeter. He also was very hesitant to work inside the crater due to the possibility of getting stuck. Therefore, the chunky clay debris was backfilled with very little compaction.

The repair team backfilled the crater with debris to approximately 12 to 15 inches below the pavement surface. The



Figure 18. Crater 1

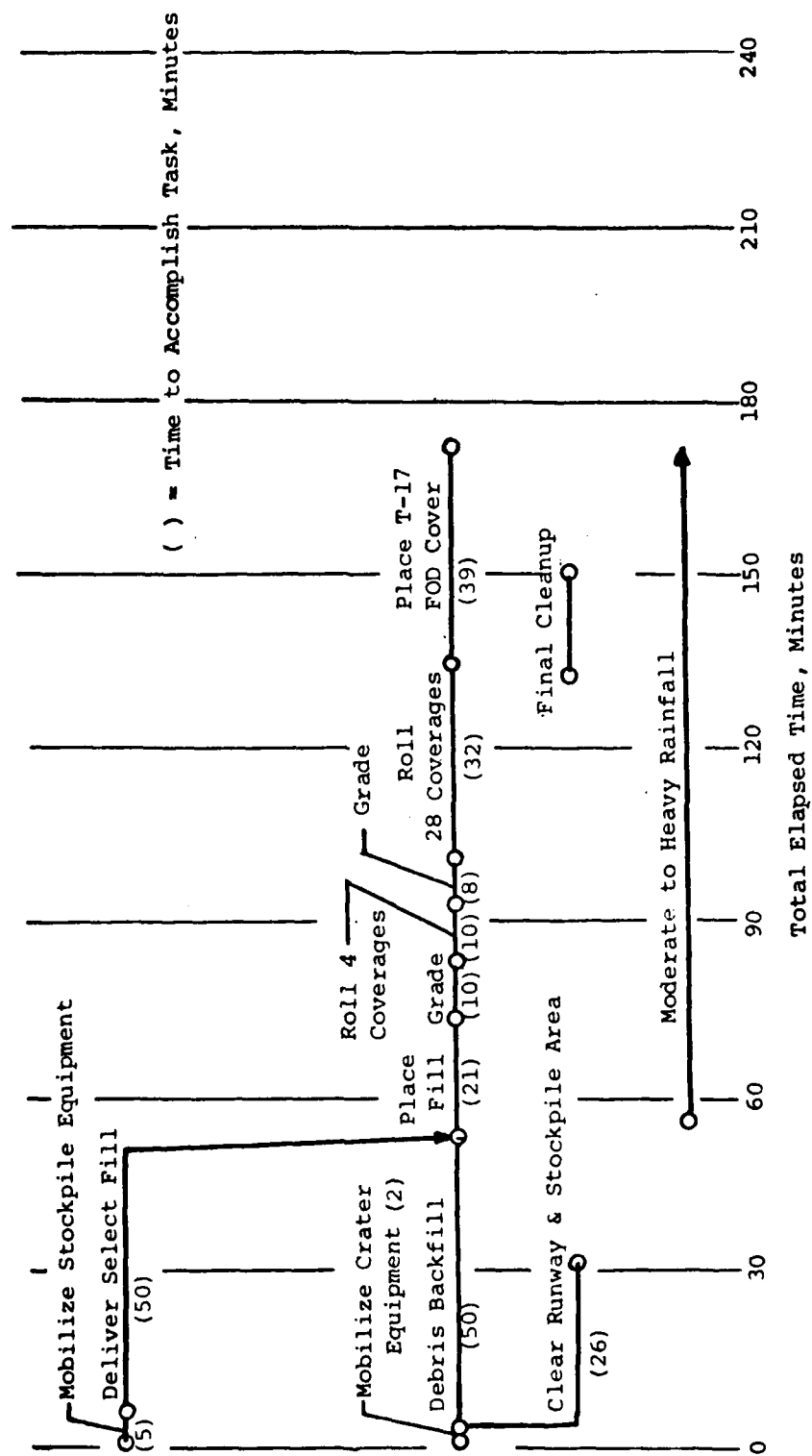


Figure 19. Work Flow Diagram-Crater 1

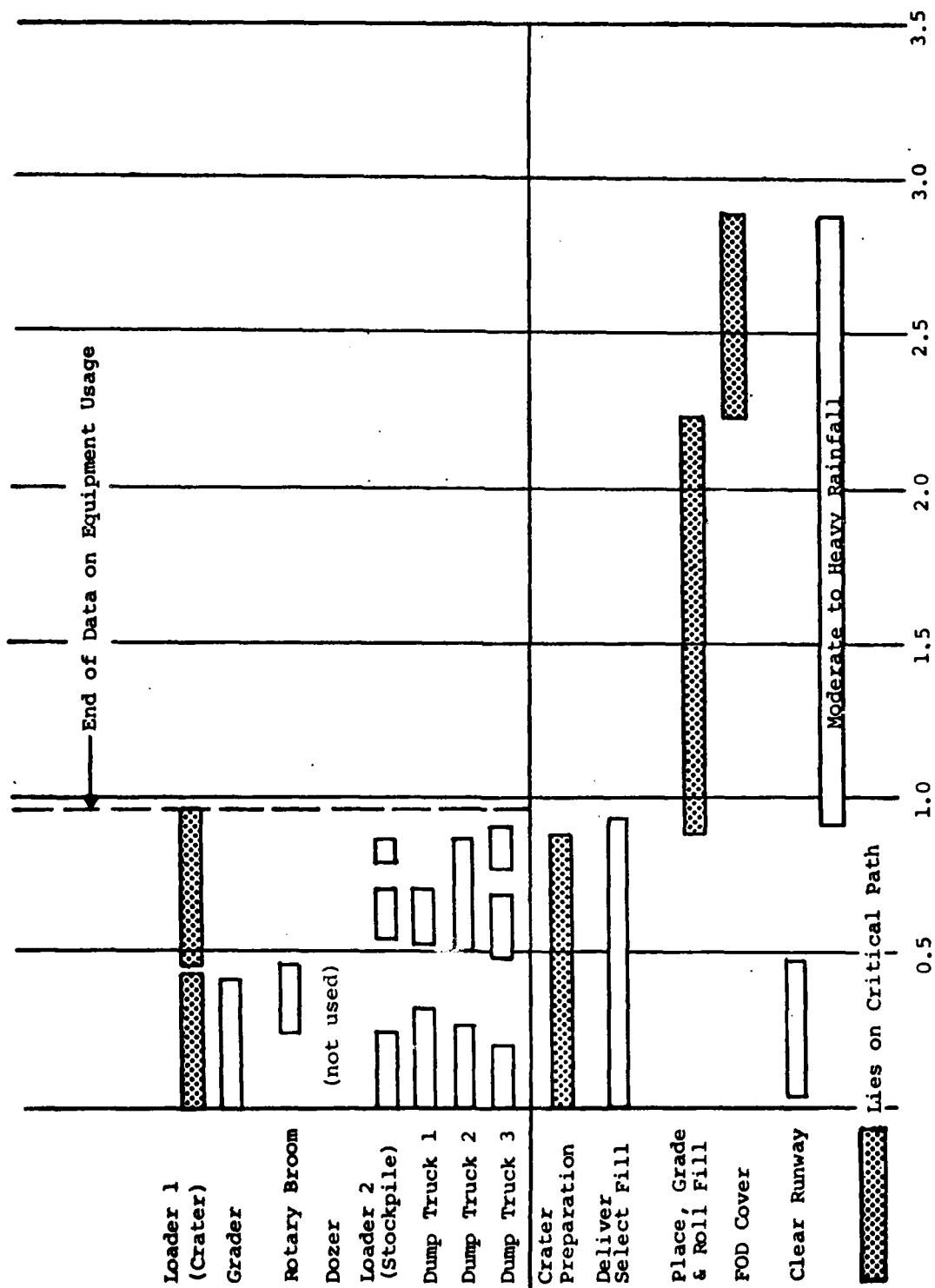


Figure 20. Equipment Operation and Repair Tasks-Crater 1

plan was to build a working platform with crushed limestone on top of the clay backfill, and then compact the clay using the loader tires to the required 24-inch depth as shown in Figure 21. However, the clay failed to significantly compact under the loader tire loads. This resulted in a debris backfill that was approximately 15 inches from the surface and poorly compacted. The repair team OIC reported seeing voids in the backfill as a result of insufficient compaction of the clay chunks.

Another significant problem in the debris backfill phase of the repair was the removal of debris along the edges of the crater. The size of the bucket on the loader precluded effective edge cleaning, requiring a large amount of handwork along the crater perimeter (Figure 22). This problem was seen throughout the Small Crater Test.

As can be seen in Figure 19, the debris backfill phase took 50 minutes, far too long for an expedient repair. This time can be attributed to an accumulation of the reasons discussed above (i.e., crew inexperience, lack of aggressiveness, instructions to emphasize quality over speed, problems with handling the chunky clay, and excessive handwork along the crater edges). Practice in crater repair would greatly enhance the speed of this phase. Another potential improvement also was evident while observing the repair team. By permitting the team to place more than 24 inches of crushed limestone in the crater, it would allow them to quickly dispose of the debris in the easiest manner (either into the crater or to the side of the runway). Much time was lost in handling the debris and trying to obtain exactly 24 inches of select fill (although actually only 15 inches were obtained). Had the repair team simply removed or pushed aside the troublesome clay chunks, they could have saved a considerable amount of time. The relatively modest quantities of fill associated with a small crater make this strategy both feasible and attractive. However, this approach would be inadvisable for large deep craters due to the amount of select fill and the length of time for delivery required.

Several other problems were also encountered in the early phases of the repair. The delivery of the select fill proceeded fairly well and was of minor concern due to the relatively small amount required, as compared with the large craters in AFR 93-2. The major problem with this task was in the location of the crater stockpile, which was approximately 80 feet from the crater itself. This distance was more than necessary to allow crater operations to continue unhampered, and the excess distance increased the time required to place the select fill into the crater.

Another problem encountered was with the hand-held radios that were supplied to key members of the repair team. The radios were totally ineffective due to very limited range (approximately



Figure 21. Compacting Debris Backfill with the Loader



Figure 22. Cleaning the Debris Around the Crater Edges

1/2 mile), intermittent operation, and excessive noise from the repair equipment. In fact, the noise prevented the OIC from being summoned by radio even though it was carried in his belt. The fact that the radios were hand-held also retarded the movements of the key personnel. While communications among team members were considered vital, use of the radios was quickly discontinued.

Identification of upheaved pavement requiring removal was accomplished using a modified 2- x 6- inch board 8 feet long with a 1.5 percent slope over 4 feet (Figure 23). Using this board, no significant upheaval except the obviously fractured area immediately around the crater perimeter was detected on Craters 1 through 5. On Crater 1, however, the test was interrupted for a period of time to allow testing of possible equipment for removing upheaved pavement. The equipment tested included:

- (1) The dozer blade.
- (2) The ripper tooth on the dozer.
- (3) The loader bucket.
- (4) The rough-terrain forklift (i.e., the loader outfitted with forks).

The dozer blade was found too large for the crater, as shown in Figure 24. The blade only contacted the pavement at two points, and the dozer was unable to be positioned properly for removing the pavement due to its large size relative to the crater (the dozer was almost as big as the crater and moved awkwardly inside the crater). Also, the dozer was not operating at its full power, as mentioned in Section II. The loader, with either the bucket or forks, lacked sufficient power and weight to remove the pavement. Only the ripper tooth was able to achieve any success in removing pavement (Figure 25). The ripper was able to chip away the pavement in one- to two-foot chunks, a very inefficient and time-consuming process. The current BDR kits do not have any rapid and efficient means for removing upheaved pavement from small craters.

Following the upheaval removal tests, the repair resumed with placement of the crushed limestone, 52 minutes into the repair as shown in Figure 20. Three minutes later a very heavy rain began which infiltrated the voids in the clay backfill and also thoroughly soaked the crushed limestone fill. Nevertheless, the repair proceeded although the video tape, time-lapse movie, and equipment observation data were halted by the rain.

After placement of the crushed limestone fill, the grader leveled the limestone to six inches above the surrounding pavement. Ten minutes were required for this operation. For the initial leveling operation, a rough grade is all that is required since the repair will be regraded after the initial four coverages of the vibratory roller. Hence, this grading operation should



Figure 23. Checking for Upheaved Pavement

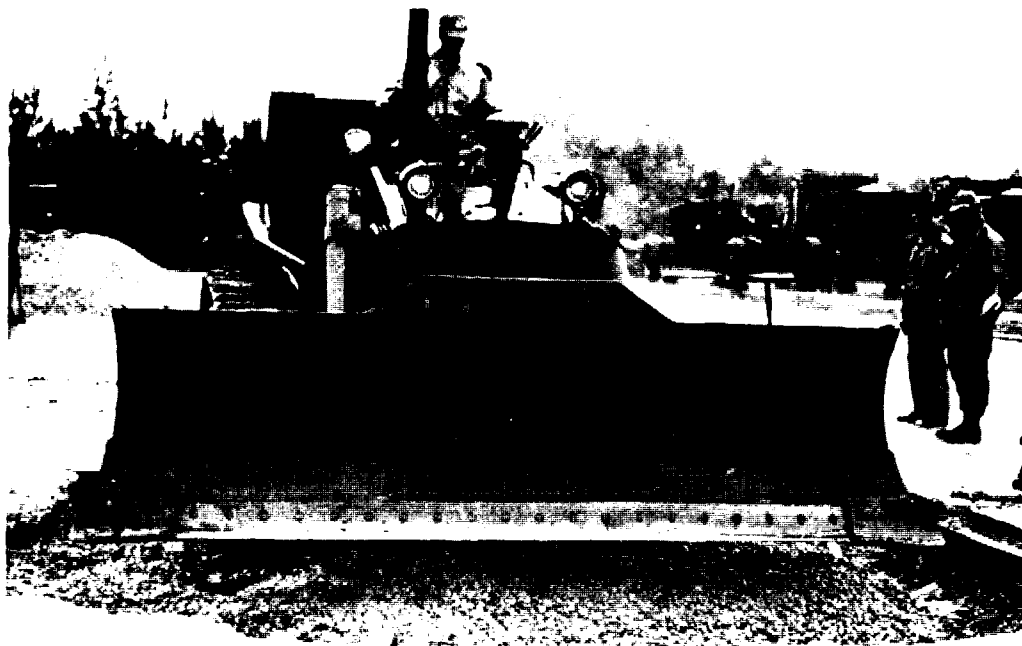


Figure 24. The Dozer Inside a Small Crater

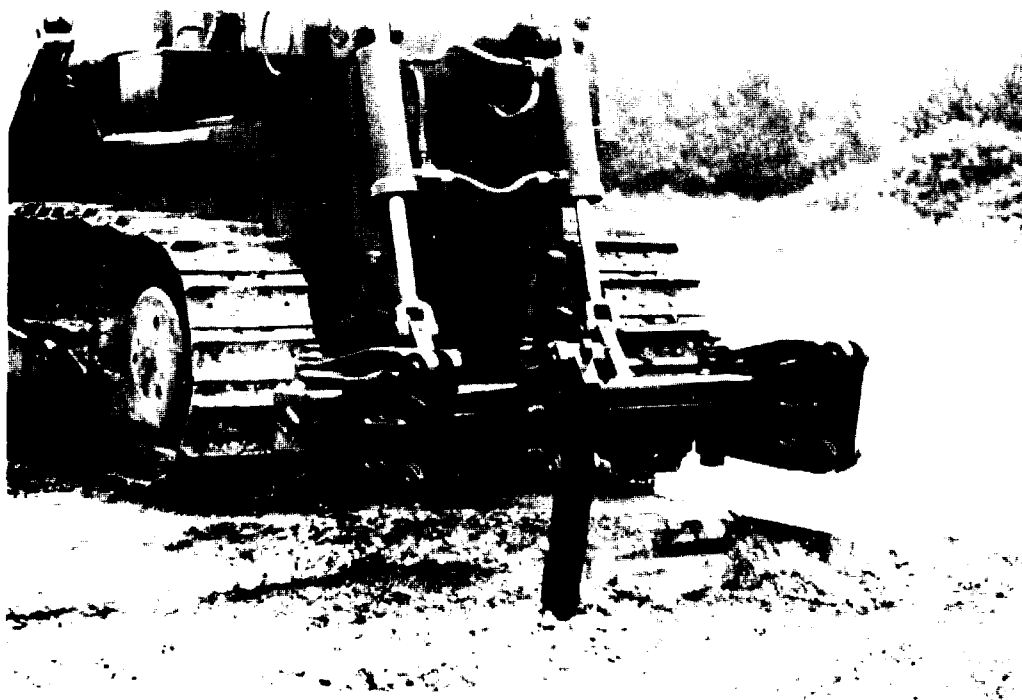


Figure 25. Removing Upheaved Pavement With the Ripper Tooth

not take over two to three minutes for a small crater using either the loader or the grader.

After the repair was leveled, the initial roller coverages were applied (Figure 26). The operator did not stop the vibrator prior to rolling onto the surrounding concrete. After several coverages it was noticed that the concrete adjacent to the crater was cracking and spalling, as shown in Figure 27. The operator was informed of the problem and with a little practice was able to time the vibrator to coincide with the edge of the repair, causing no further problem.

After the first four roller coverages were applied, the patch was regraded and the remaining 28 roller coverages were applied. Then the T-17 membrane FOD cover was placed over the repaired crater. The T-17 membrane is a 0.042-inch thick airfield surfacing manufactured from neoprene-coated nylon material. The membrane was anchored to the concrete by wrapping the edges around four-inch-wide strips of 1/4-inch steel ten feet long, and explosively nailing the membrane and steel to the concrete pavement with a .38 caliber Ramset® gun (Figure 28), completing the repair of the crater. Total time (net) for the entire repair was 172 minutes, including 39 minutes for placement of the FOD cover.

#### b. Crater 3 - Timed Repair

Crater 3, located in the asphalt portion of the test pad, was a timed repair using the crushed limestone method. As can be seen in Figure 29, Crater 3 had a significant amount of fallback. This resulted in a rather shallow crater that required deepening and careful compaction. The repair team's instructions were slightly modified to permit more than 24 inches of crushed limestone. This allowed the repair team OIC to determine the best approach to handling the debris backfill. Figures 30 and 31 graphically show the sequence of events and the equipment usage for Crater 3.

The loader operator used for Crater 1 was replaced with a more experienced operator, and the improvement was immediately apparent in the way he quickly and aggressively worked on the debris around and inside the crater. While the loader was clearing debris from inside and around the crater, the grader first cleared an area for the crushed limestone stockpile, and then continued to clear the rest of the test pad. Unfortunately, this time the stockpile area was placed too close to the crater, being only 12 feet from the crater's edge. The stockpile presented an obstacle to all work around the crater, unnecessarily impeding the movement of repair equipment.

At the request of the test monitors, the repair team attempted to use the dozer during the debris backfill phase. However, again the dozer was too big and awkward for small crater



Figure 26. Compacting the Crushed Limestone



Figure 27. Concrete Spall Caused by the Vibratory Roller



Figure 28. Anchoring the T-17 Membrane FOD Cover



Figure 29. Crater 3 After Clearing of Debris



Figure 28. Anchoring the T-17 Membrane FOD Cover

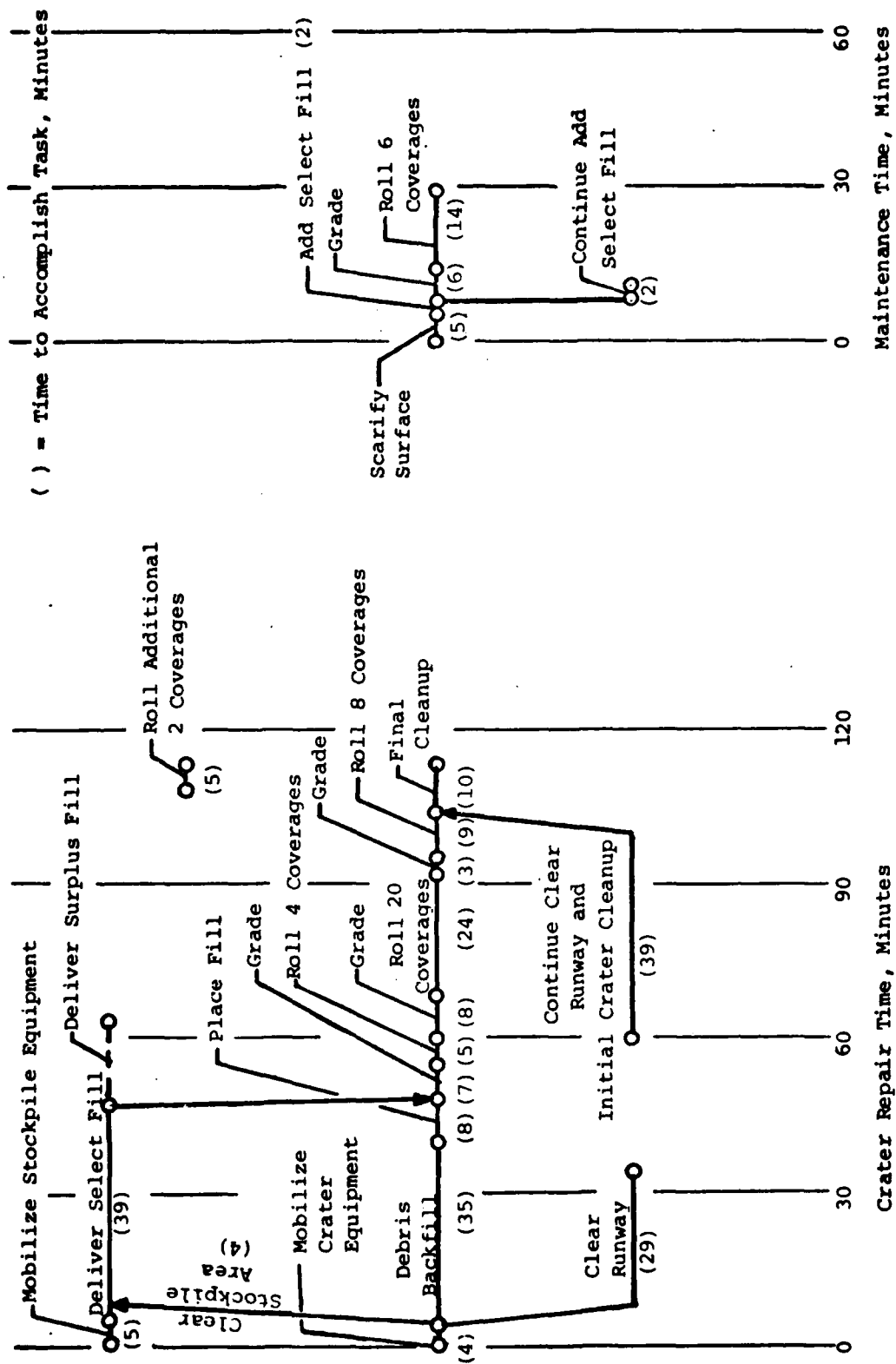


Figure 30. Work Flow Diagram-Crater 3



Figure 31. Equipment Operation and Repair Tasks- Crater 3

work and after six minutes yielded to the better-suited loader. As in Crater 1, a significant amount of shovel work was required to clear the debris around the crater edges.

After the debris backfill phase was completed, crushed limestone was placed in the crater to an average depth of approximately 2-1/2 feet. Then the grader was used to rough level the select fill. As in Crater 1, too much care was taken to insure a level repair at this point in the repair.

The initial coverages of the vibratory roller were applied, then the patch was regraded with the grader and the main compaction applied. During the main compaction phase, the roller did not follow distinct roller lanes, causing the repair to receive non-uniform compaction. Such a compaction pattern could conceivably result in areas not receiving enough compaction, leading to a repair failure. This demonstrates once again the importance of proper training for the crater repair teams. As can be seen in Figure 31, the compaction of the repair was momentarily interrupted to allow for additional grading due to the OIC's dissatisfaction with the repair's smoothness. The additional two coverages at the end of the repair were applied to smooth out some roller marks left in the crushed limestone surface.

The sweeping of the area around the crater presented additional problems for the repair team. The rotary broom had mechanical troubles and frequently stopped running. The inexperienced broom operators also failed to follow an orderly sweeping pattern, often sweeping dirt into previously swept areas. These problems, plus the bothersome dust cloud created by the broom (Figure 32), made the sweeping operation almost useless for Crater 3. However, as the Small Crater Test progressed, the operators became reasonably proficient in sweeping the pavement, despite mechanical problems with the equipment.

The repair of Crater 3 required 113 minutes. Immediately following the repair, F-4 loadcart trafficking was applied. After 100 coverages (960 passes) of the loadcart had been placed on Crater 3, it was decided that maintenance was required to add additional crushed limestone due to consolidation of the repair.

The steps in the maintenance operation were very simple. First, the grader's scarifying teeth were used to loosen the crushed limestone surface. The next step was to dump fresh crushed limestone on the scarified surface, and then grade the stone to approximately one inch above the surrounding pavement. Finally, the vibratory roller placed six coverages on the repair. Maintenance of the repair required 27 minutes.

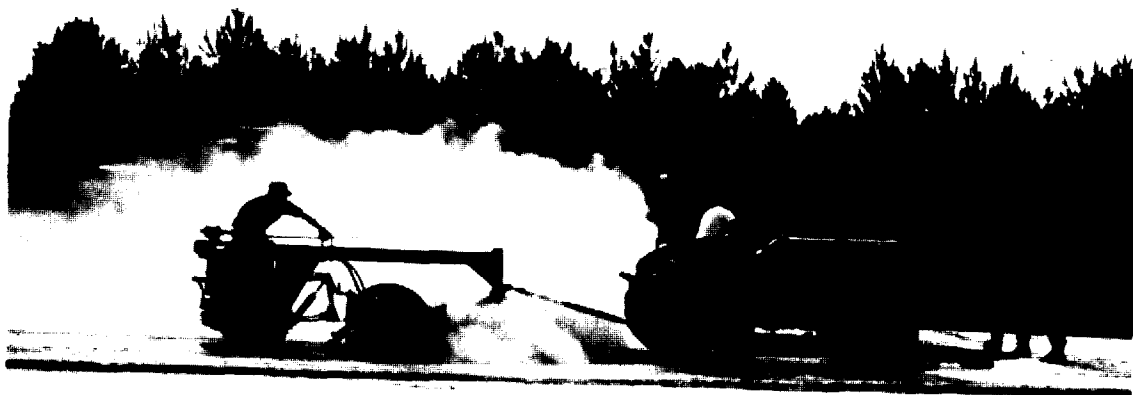


Figure 32. Towed Rotary Broom

### c. Craters 5 and 6 - Timed Simultaneous Repair

The final test of the crushed limestone repair involved the timed simultaneous repair of two craters. The purpose of this test was to determine the effects of one repair team having to give its attention to more than one crater. The test was also designed to determine the effects of cratering centered at slab joints and corners versus craters located in the center of slabs. Two major changes were made in the equipment allocations for this test: three loaders were used instead of two, and two vibratory rollers were used instead of one. Otherwise, the equipment remained the same as in previous tests.

Crater 5 (Figure 33) was located at the joint between two asphalt-overlaid slabs in the northeast portion of the test pad. This crater was slightly larger than the previous four craters as shown in Table 1, and had no significant amount of upheaval. Crater 6 (Figure 34) was located at the corner of four concrete slabs in the northwest portion of the test pad centered approximately 75 feet from Crater 5. This crater was the largest of the craters in the Small Crater Test due to the significant amount of upheaval requiring removal. The removal of four slabs of pavement was required to meet the upheaved pavement criteria as measured in the field.

Figures 35 and 36 graphically show the time data for Craters 5 and 6. The repair time for this test was 171 minutes, including 39 minutes for removal of the upheaved pavement around Crater 6. The practice and experience gained by the repair team from Craters 1 through 4 resulted in no real problems in repairing these craters, aside from the upheaval removal.

The upheaved pavement around Crater 6 presented a problem to the repair team. The loader initially attempted to break out the pavement using its bucket, but a lack of sufficient power immediately became evident. The dozer then tried to use its blade to push out the upheaval and also found its power deficient. As was found in the Crater 1 test, only the dozer's ripper tooth was able to break out any pavement. This removal was accomplished by hooking the pavement edge with the tooth while sitting on the pavement itself, and prying the pavement up, as was shown in Figure 25. With a little practice, the dozer operator was able to snap out pieces of the upheaved pavement that were four to five feet across. The dozer was too small both in weight and horsepower to perform this task efficiently, however. The operator often hydraulically lifted the front end of the dozer several feet into the air and worked the blade to break out small chunks of pavement (Figure 37). The process was intolerably slow, given the constraints of an expedient repair system.

The remaining portions of the repair proceeded smoothly and more or less as expected. The repair team OIC reported that



Figure 33. Crater 5



Figure 34. Crater 6

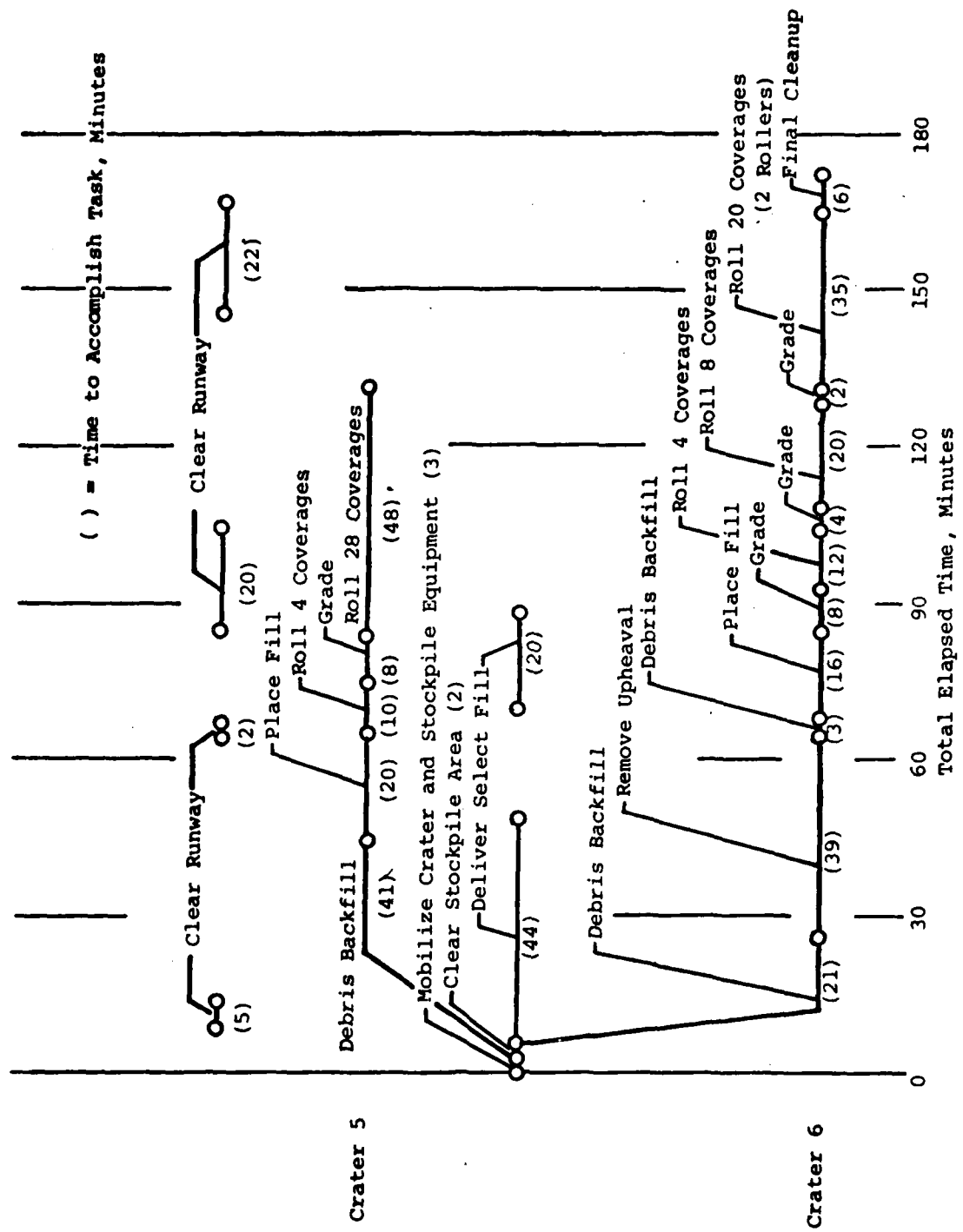


Figure 35. Work Flow Diagram - Craters 5 and 6

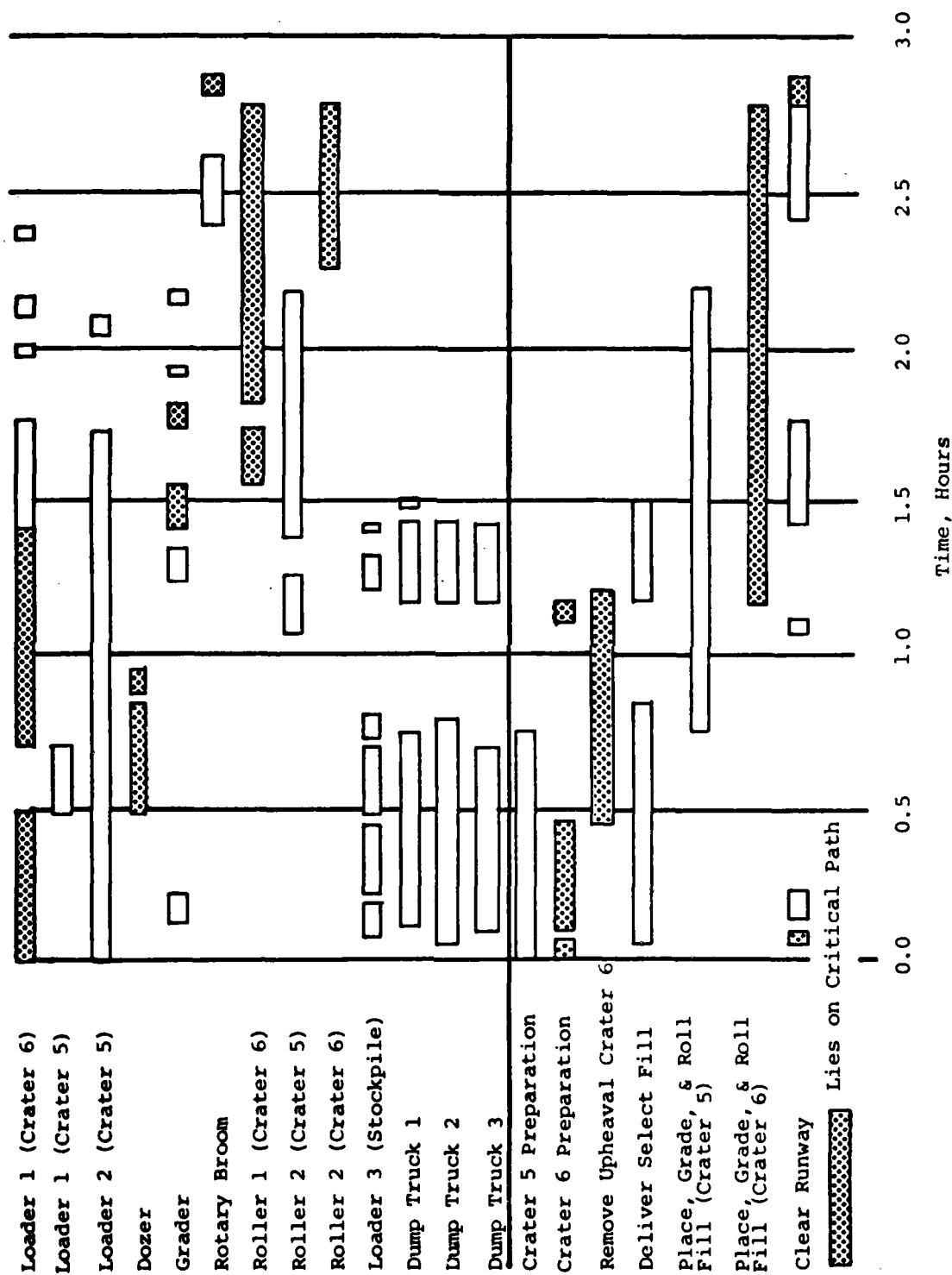


Figure 36. Equipment Operation and Repair Tasks-Craters 5 and 6



Figure 37. Dozer Too Small for Upheaval Removal

Crater 5 received approximately 36 inches of select fill, and Crater 6 received 18 to 30 inches of select fill. The OIC felt that the portions of the repair with only 18 inches of fill over the subgrade would not be a problem. A significant amount of crushed limestone had been mixed in with the clay subgrade during the debris backfill phase of the repair, providing a better-than-average backfill for Crater 6.

Crater 5 was finished 41 minutes ahead of Crater 6 due to the lack of upheaved pavement and also due to the assistance of the Crater 6 loader for 13 minutes while the dozer worked alone on upheaval at Crater 6. After compaction was completed, the Crater 5 roller went over to Crater 6, and the two rollers simultaneously compacted Crater 6 for 31 minutes.

## 2. POLYMER-CONCRETE REPAIR

### a. Crater 2 - Procedural Practice Repair

The second crater test performed during the Small Crater Test was a practice repair using polymer-concrete. As in Crater 1 the repair team was briefed on repair procedures and told to emphasize repair quality over time. Crater 2 was a relatively shallow crater with a large amount of fallback material, as shown in Figure 38.

For Crater 2 the dump trucks were preloaded with the two-inch uniform aggregate. This was done in order to keep the aggregate dry, as the polymeric bond is weakened in the presence of moisture. As a result, the stockpile loader was free to assist at the crater site, giving the repair team two loaders. The repair team OIC elected to use one of the loaders (primary) for work in the crater and the other loader (secondary) for clearing the runway. This usage is reflected in Figures 39 and 40, the time charts for Crater 2. For this test the tractor-trailer (lowboy) was also preloaded with pallets of the polymer material. As can be seen in Figure 40, neither of these preloadings influenced the task times; the secondary loader, the lowboy, the dump trucks, and the forklift were all utilized a relatively small portion of the total repair time and were all performing non-critical path activities.

As in the crushed limestone repair, the initial critical path activities are equipment mobilization and debris backfill of the crater. The repair team was instructed to bring the debris up to within 8 to 10 inches of the pavement surface and then to halt the repair prior to placing the uniform aggregate into the crater. This interruption was to allow field testing of the subgrade for determination of the CBR and modulus of subgrade reaction, as discussed in Section IV.

During the debris backfill phase, the repair team attempted to use the dozer for compaction of the debris backfill



Figure 38. Crater 2

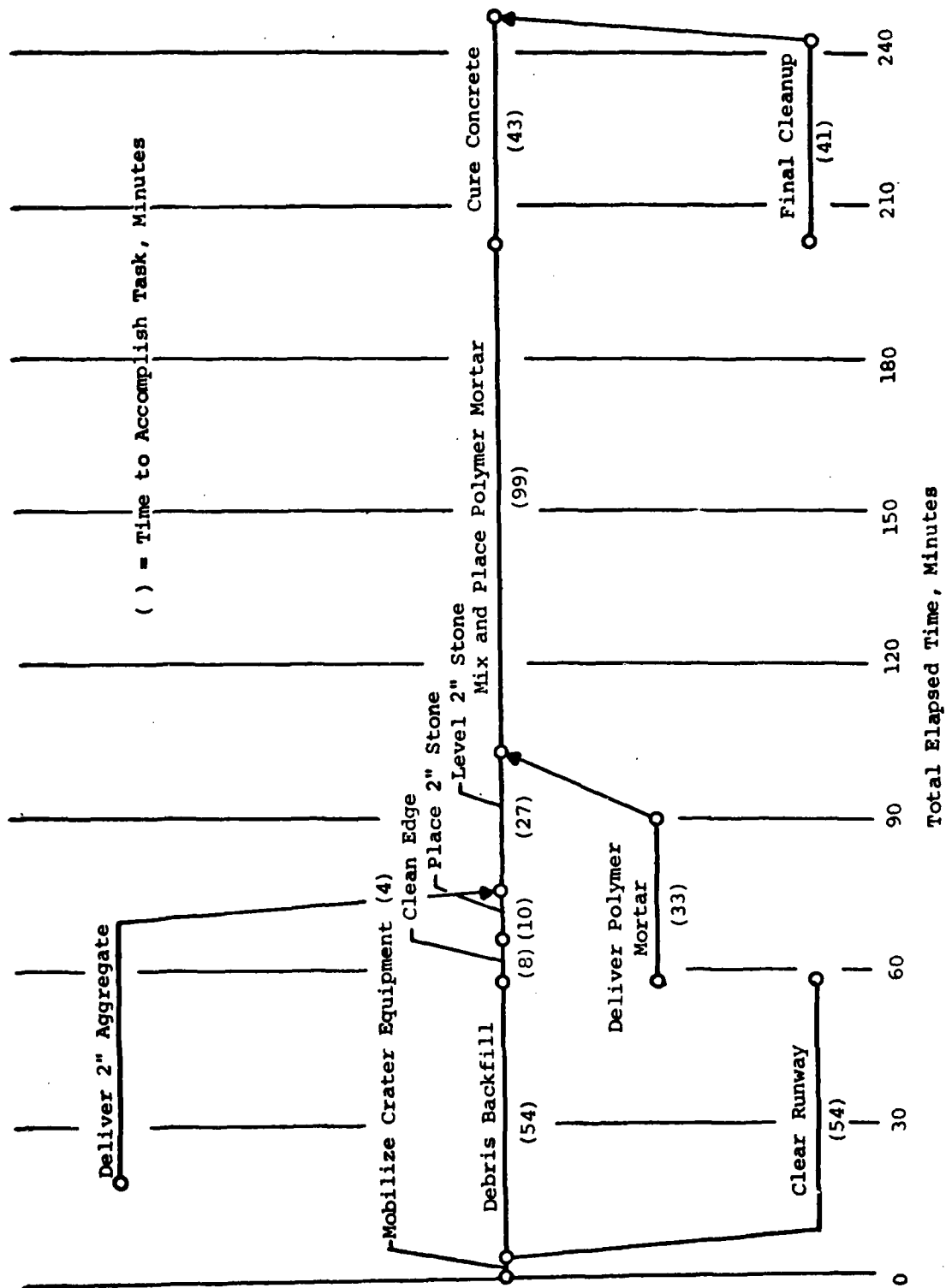


Figure 39. Work Flow Diagram - Crater 2

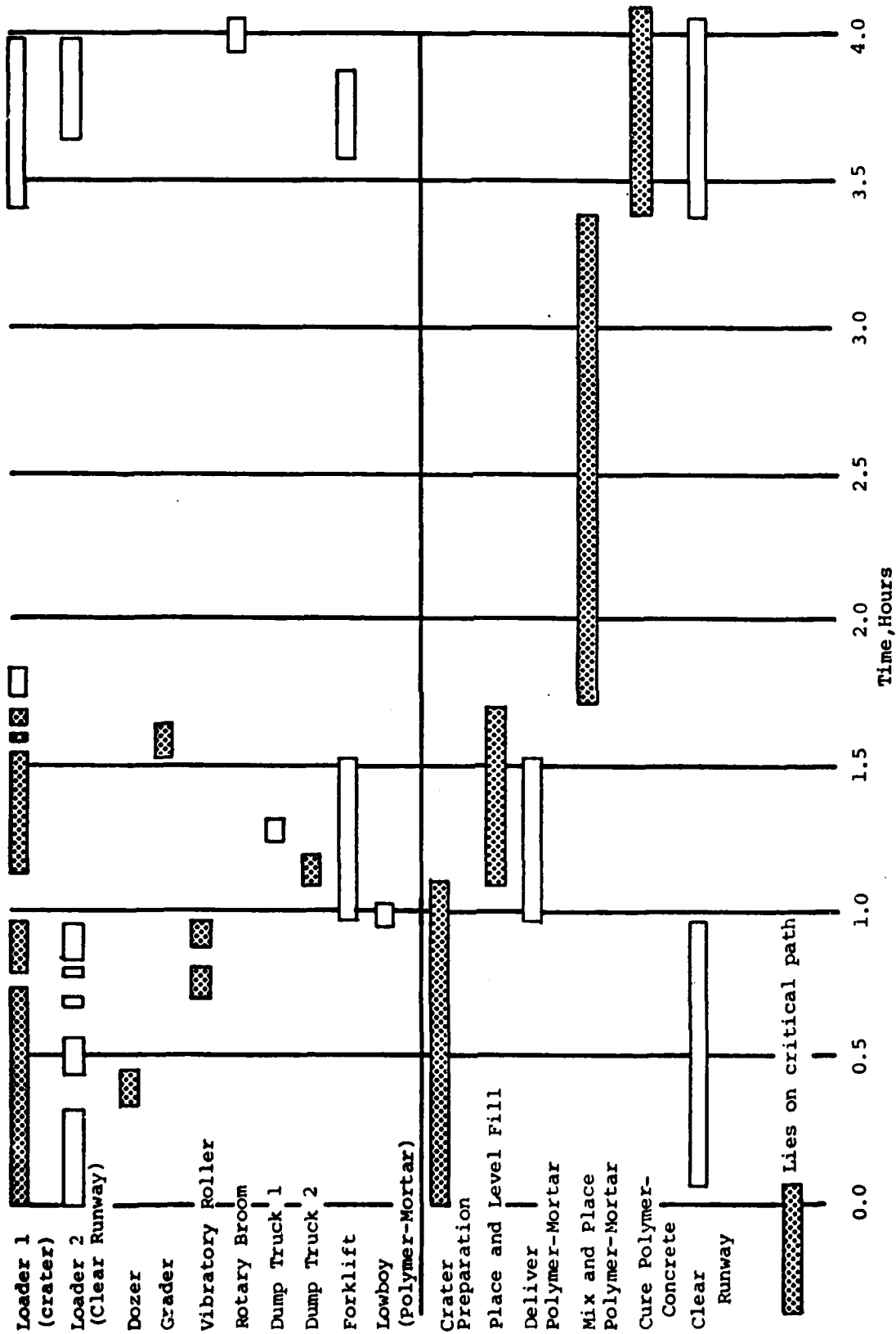


Figure 40. Equipment Operation and Repair Tasks-Crater 2

and for removal of the shattered pavement around the crater. However, due to its large physical size relative to the crater and its lack of power, the dozer proved very inefficient and was dismissed after seven minutes. Additional time was also lost due to difficulty in obtaining sufficient debris to fill the crater to the desired depth. The loader operator had immediately cleared the larger pavement slabs and some of the debris to the side of the runway upon arrival at the crater site. Thus, the loader operator ran out of material to push back into the crater and had to go to the pavement edge to get additional debris to backfill the crater. The loader operator was also forced to use some of the berm along the pavement edge in order to avoid placing the large concrete slabs into the crater. As discussed in the subsection on the crushed limestone repair, it would probably be wise to specify a minimum depth for the 2-inch stone and allow the repair team OIC/NCOIC to determine the most expedient method of filling the crater.

Figure 41 shows the hand and shovel work that was required to clean the loose material around the crater walls. This time-consuming task was especially important for the polymer-concrete repair to insure that all of the loose concrete was removed and a good bond obtained between the patch and the surrounding pavement. The debris subgrade was then compacted with the vibratory roller, as shown in Figure 42. The repair team used the roller for leveling the subgrade as well as compaction. In retrospect, the decision to use the roller was probably unnecessary due to the fact that the subgrade can be satisfactorily compacted and leveled with the loader during the debris backfill phase. Nevertheless, after a total of 54 minutes of work, the repair team had filled the crater with debris to within 8 to 10 inches of the pavement surface.

The next activity on the critical path was to clean all loose debris from the edges of the pavement. This was accomplished by using an air compressor on the south and east sides of the crater (Figure 43) and brooms on the north and west sides. Two methods were used to determine if one method of cleaning the edges was superior to the other, either in terms of the actual cleaning, actual performance under trafficking, or speed. It was found that while both methods of cleaning performed comparably under trafficking, the air compressor was preferred for its faster and more thorough cleaning. Also, two of the three brooms broke while sweeping the crater edges.

While the crater edges were being cleaned, the forklift began unloading the pallets of polymer material from the lowboy. As can be seen in Figure 44, the bags of Silikal® polymer-mortar were stacked unbound on the pallets. This presented a problem to the forklift operator, as bags of the powder kept falling off the pallet during handling. An improved packaging method would be required if this type of repair is adopted for use by the Air Force.

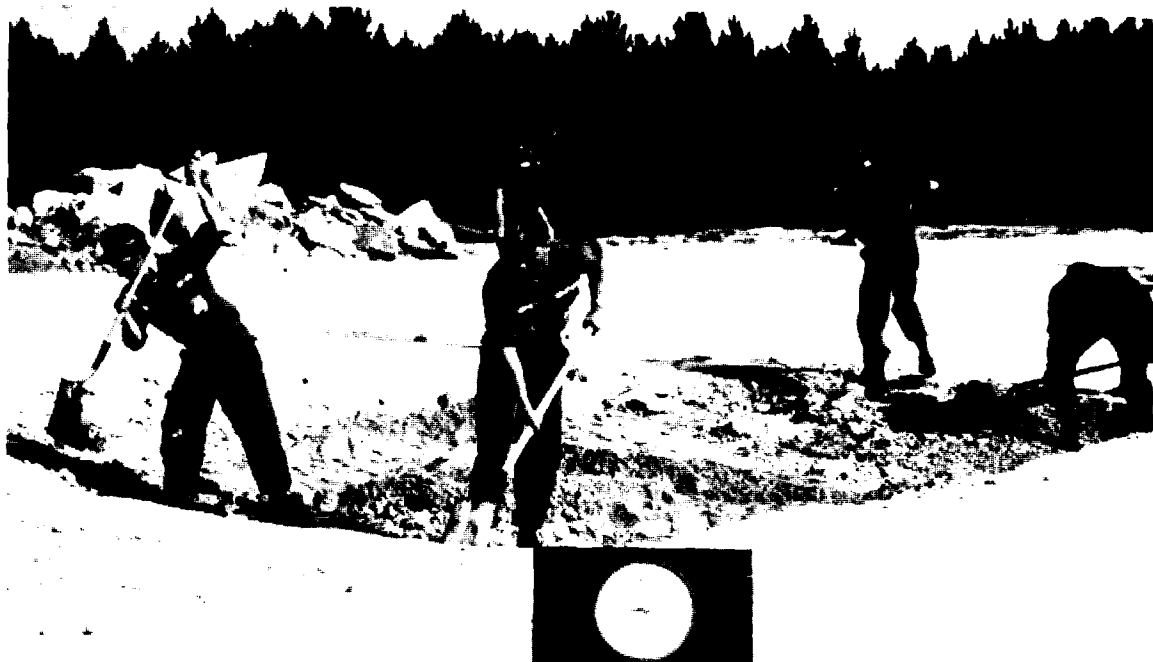


Figure 41. Manually Cleaning the Crater Edges

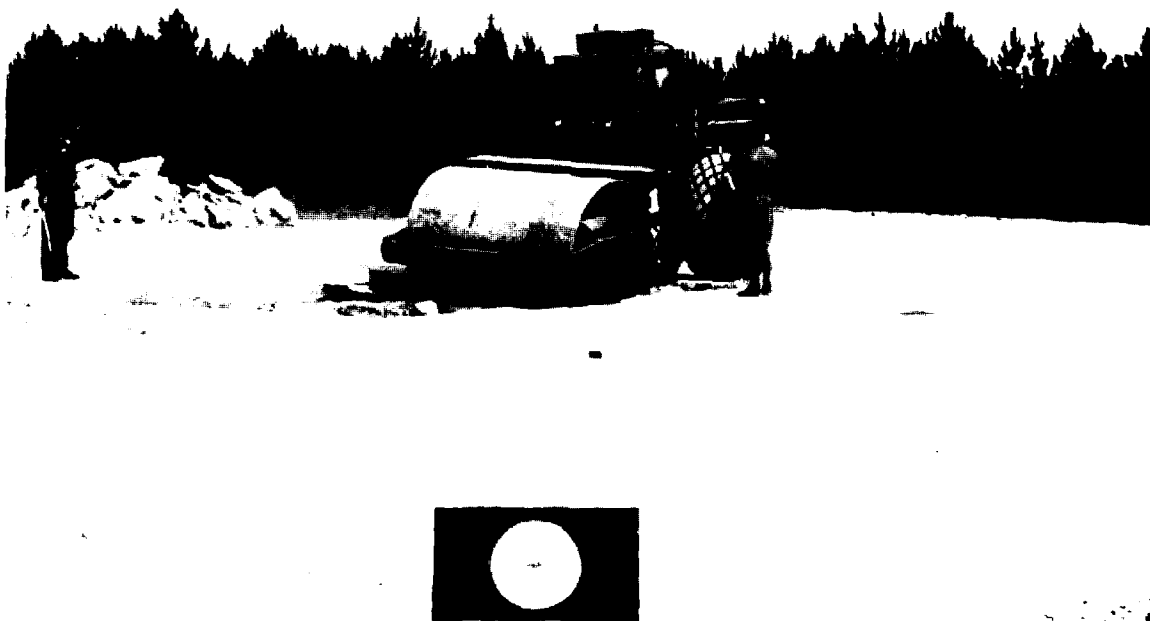


Figure 42. Compacting and Leveling the Debris With the Vibratory Roller



Figure 43. Cleaning the Pavement Edges With the Air Compressor



Figure 44. Pallet of Silikal®

After the crater edges had been cleaned, the two-inch uniform aggregate was dumped into the crater and leveled. The leveling of the uniform aggregate proved very difficult due to its tendency to roll and shove inside the crater. The grader operator was unable to satisfactorily level the stone (partially due to inexperience), and the repair team was finally forced to use a screed beam and shovels to obtain the final grade, as shown in Figure 45. Leveling of the uniform aggregate required 27 minutes to complete.

After the uniform aggregate was in place, the mixing and placing of the polymer-mortar was begun, as shown in Figure 46. During this phase the repair team was required to use eye goggles and rubber gloves for protection from the toxic chemicals. Fire extinguishers were placed nearby and smoking was prohibited, as the liquid component is a Class I flammable material.

The beginning of the mixing and placing operation was slowed somewhat due to having to open the bags of mortar and prepare them for mixing. This delay was unnecessary since ample time and manpower for mortar preparation was available while the uniform aggregate was being placed and leveled. This planning oversight was corrected for the second polymer concrete test.

The thirteen-man crew organized itself into one supervisor (OIC), two screeders, and ten laborers. The placing of the mortar proceeded in a somewhat disorderly fashion, with each laborer responsible for opening, mixing, and pouring his own bags of Silikal®. Problems were also encountered with screeding the polymer-concrete. A 2 by 6-inch by 24-foot wooden screed was used. As the placing of the mortar proceeded, the screed became heavily caked with the mortar, making it very heavy and cumbersome. The screeding operation also lagged the pouring of the mortar by 2 to 3 linear feet. In the over 90°F ambient temperature, the initial setting of the polymer concrete had already begun before any screeding was applied. The delayed screeding, along with an occasional poorly mixed bag of mortar, resulted in the rough, but functional, finish shown in Figure 47. This manpower intensive phase of the Crater 2 repair required 99 minutes and 356 bags of polymer-mortar (96 cubic feet). This represents a placement rate of 0.36 bag per minute per laborer or 0.38 square foot per minute per laborer.

The polymer-concrete was allowed to cure for 43 minutes following placement. During this time the tired repair team cleared the crater area of the extensive debris caused by the bags of polymer-mortar (Figure 48). The entire repair required 4 hours 5 minutes (245 minutes) to complete.

#### b. Crater 4 - Timed Repair

Crater 4 was a timed repair of the polymer-concrete crater repair method. As was done for Crater 2, the pallets of



Figure 45. Leveling the Uniform Aggregate by Hand

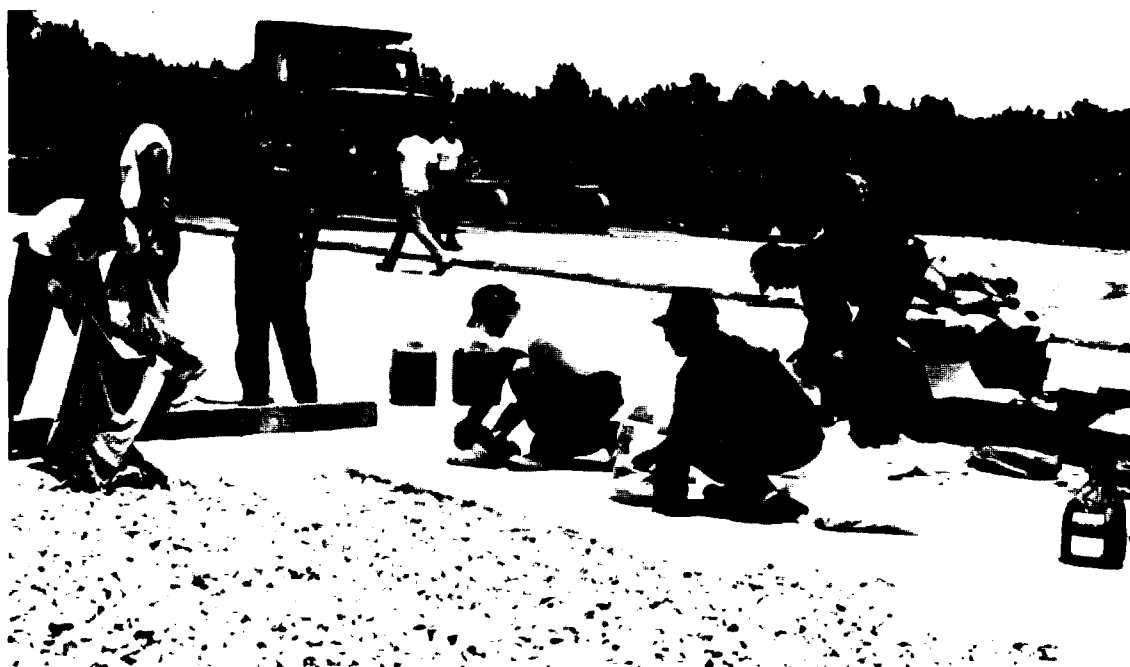


Figure 46. Mixing and Placing the Polymer-Mortar



Figure 47. Rough Polymer-Concrete Finish - Crater 2



Figure 48. Debris From Polymer-Concrete Repair

polymer powder were preloaded on the lowboy. Two of the dump trucks were also preloaded, one with crushed limestone and the other with the remaining available two-inch uniform aggregate. The crushed limestone was to be used to help supplement the debris backfill to avoid any delays associated with insufficient debris backfill material, as had occurred in the Crater 2 repair. Figures 49 and 50 are the time charts for the Crater 4 repair.

The crater to be repaired was an unusually large crater in the asphalt portion of the test pad. As shown in Figure 51, this crater was blown clean, even to the point of undercutting the surrounding subgrade. Upon arrival at the crater site, the repair team OIC decided to push most of the debris to the runway edge and use crushed limestone for the majority of the backfill material. However, this decision (that was supposed to save time) resulted in a time penalty since more crushed limestone was required than was preloaded in the dump truck. A significant delay was encountered while additional crushed limestone was loaded in the dump truck and delivered to the test site. This delay occurred due to the limited quantity of uniform aggregate available for the test; otherwise, the entire crater could have simply been filled with the uniform aggregate, causing no delays.

After the debris backfill portion of the repair was completed and the crater edge was cleaned with the air compressor, the uniform aggregate was placed in the crater and leveled. This activity, while much improved over Crater 2, still required 16 minutes to complete. A faster and easier method of leveling the uniform aggregate, such as a large screed beam capable of doing the job in a single pass, should be investigated.

The next activity in the repair was the mixing and placing of polymer-mortar. In an attempt to facilitate this activity, the 13-man repair team was augmented with two additional men. The 15-man team was organized into five two-man teams, two screeders, a supervisor (OIC), and two utility men whose job was to keep the teams supplied with bags of polymer-mortar. Each two-man team was given a work station along the width of the repair. This organization is shown in operation in Figure 52.

The screeding operation was still a problem for the repair team due to mortar caking on the screed. Approximately half-way through the pouring operation, the screed was replaced with a new one. This, along with insuring that the screeding operation kept up with the pouring of the Silikal®, resulted in a much improved surface finish over that achieved in the Crater 2 repair.

The placing of the polymer mortar required 100 minutes and 464 bags of mortar (125 cubic feet). Counting the utility men as laborers, this represents a placement rate of 0.39 bag per

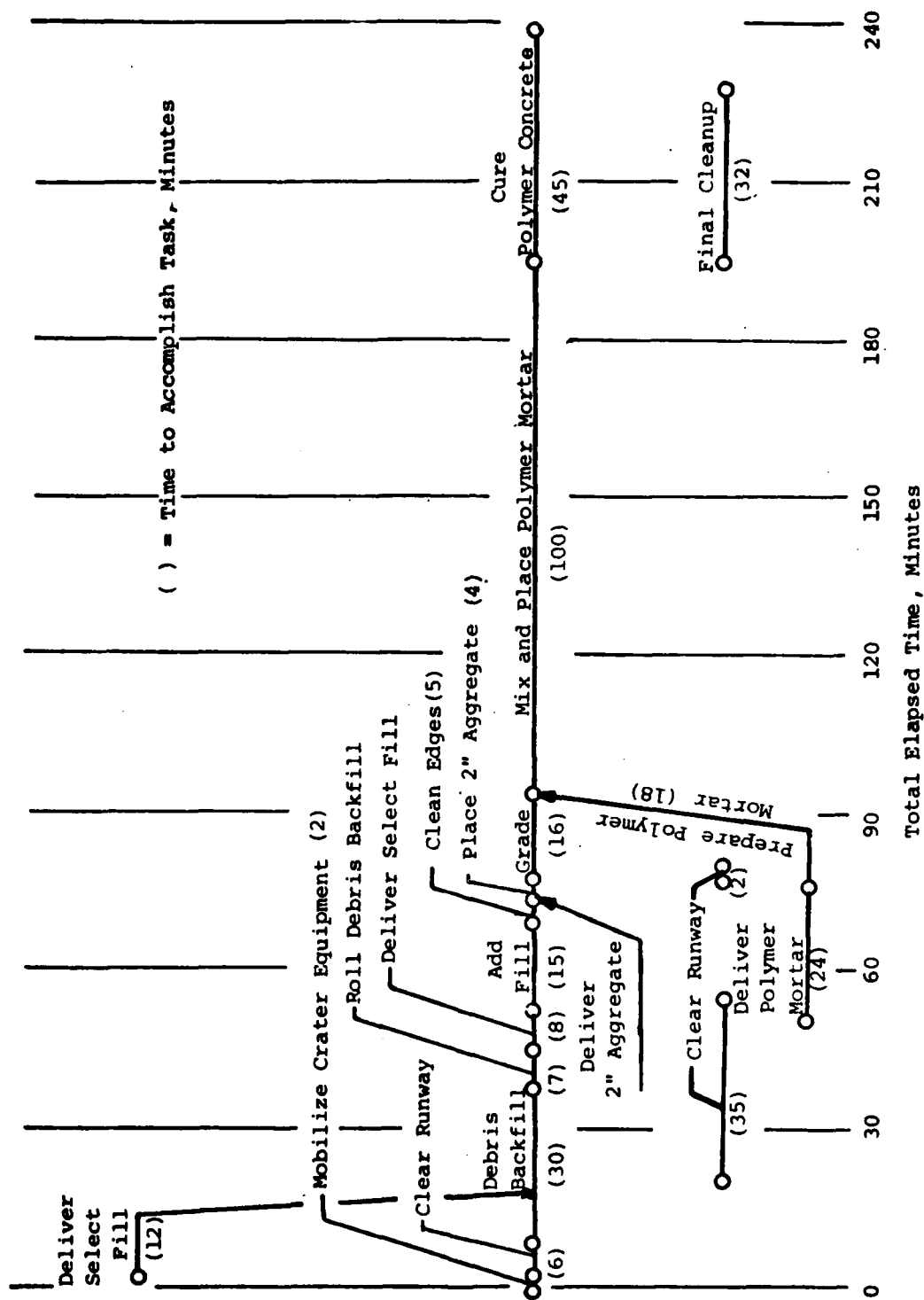


Figure 49. Work Flow Diagram - Crater 4

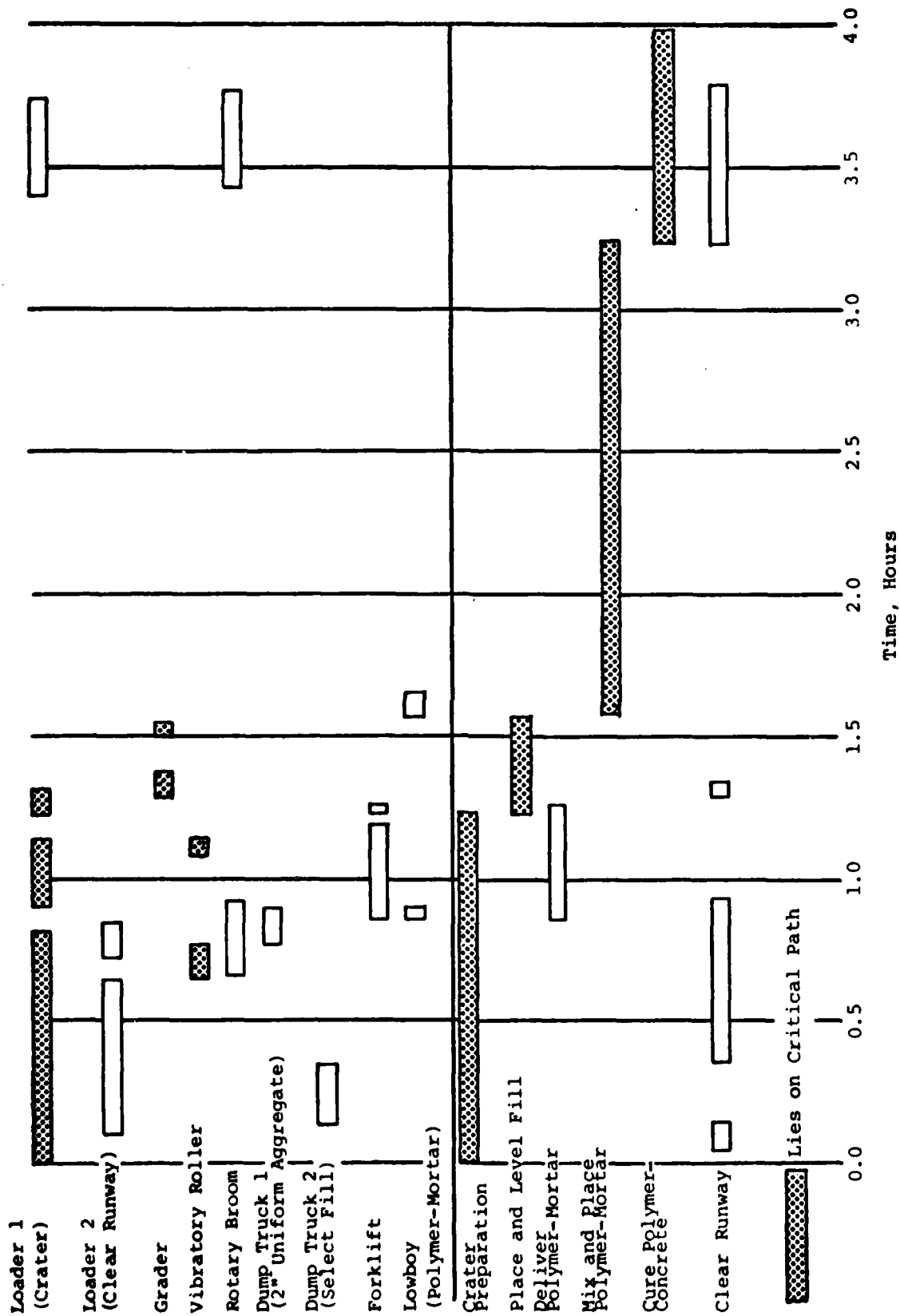


Figure 50. Equipment Operation and Repair Tasks - Crater 4



Figure 51. Crater 4



Fig. 52. Two-man Teams Mixing and Placing Silikal®

minute per laborer or 0.38 square foot per minute per laborer. Following placement of the polymer-mortar, the patch was allowed to cure 45 minutes while the final cleanup took place. The overall time required to repair Crater 4 was 3 hours 58 minutes (238 minutes).

### 3. TIME ANALYSES

Tables 4 and 5 summarize the time required for the various repair tasks and the equipment utilization times, respectively, as a percentage of the total repair time required. Also presented are the time percentages for tasks and equipment lying on the critical path for minimum repair time. These tables help to emphasize the critical tasks and equipment involved with the two repair methods.

The most time-consuming task on the critical path for the crushed limestone repair was placement of the limestone, which included grading and compacting the limestone. This task averaged over 50 percent of the repair time. The second longest task was crater preparation (including upheaval removal as required), averaging almost one-third of the repair time. The primary equipment used for these two tasks, the vibratory roller and the crater loader, performed critical path tasks an average of 58 percent and 44 percent of the time, respectively. These two pieces of equipment were the workhorses in the crushed limestone repair for small craters and, along with upheaved pavement removal equipment, should probably be the focus of any improvement made to a crushed limestone crater repair kit.

The most time-consuming and manpower intensive task on the critical path for the polymer-concrete repair was the mixing and placing of the polymer-concrete. This task required an average of 41 percent of the total repair time and used none of the heavy equipment available to the team. Assuming, however, that the mixing and placing procedure could be mechanized, and the speed of placement greatly increased (which is considered technically feasible), the tasks of crater preparation and of placing and grading the uniform aggregate will assume proportionately greater percentages of the critical path. The primary piece of equipment for accomplishing these tasks is the loader and should probably be the focus of any equipment improvements for the polymer-concrete repair kit, following the acquisition of a mechanized polymer-concrete placement system and equipment for removing upheaved pavement.

Appendix B contains graphs which, in the absence of any other data, may be useful for estimating task times for the crushed limestone repair, including:

- . Crater preparation.

TABLE 4. SUMMARY OF REPAIR TASKS\*

Repair Task	Crater Number					
	Crushed Limestone Method				Polymer-Concrete Method	
	1	3	5	6	2	4
Crater Preparation	30( 30)	35( 35)	26	16( 16)	27( 27)	31( 31)
Upheaval Removal	N/A	N/A	N/A	23( 23)	N/A	N/A
Deliver Fill Material	32	48	39**		N/A	N/A
Place, Grade and Compact (as required) fill material	47( 47)	60( 57)	50	57( 57)	15( 15)	8( 8)
FOD Cover	23( 23)	N/A	N/A	N/A	N/A	N/A
Deliver Polymer-Mortar	N/A	N/A	N/A	N/A	13	10
Mix and Place Polymer-Mortar	N/A	N/A	N/A	N/A	40( 40)	42( 42)
Cure Concrete	N/A	N/A	N/A	N/A	18( 18)	19( 19)
Clear Runway	25	69( 8)	33( 4)**		39	32

\*Values are percentage of total repair time. Values in parentheses represent the percentage of total repair time that lies on the critical path for minimum time.

\*\*This task was common to both Craters 5 and 6, which were repaired simultaneously.

TABLE 5. SUMMARY OF EQUIPMENT UTILIZATION\*

Equipment Type	Crater Number				
	Crushed Limestone Method			Polymer-Concrete Method	
	3	5	6	2	4
Loader (crater)	92( 45)	65( 42)	65( 42)	51( 34)	38( 29)
Loader (clean runway)	N/A	N/A	N/A	24	16
Dozer	5( 5)	0	15( 15)	3( 3)	0
Vibratory Roller	64( 58)	34	58( 58)**	4( 4)	4( 4)
Grader	43( 16)	15( 7)***		3( 3)	3( 3)
Rotary Broom	9	9( 2)***		3	16
Lowboy	N/A	N/A	N/A	1	3
Forklift	N/A	N/A	N/A	20	9
Loader (stockpile)	43	25***		N/A	N/A
Dump Truck I	39	32***		2	3
Dump Truck II	20	35***		2( 2)	5
Dump Truck III	39	29***		N/A	N/A

\*Values are percentage of total repair time. Values in parentheses represent the percentage of total repair time that lies on the critical path for minimum time.

\*\*This value represents one roller in use 22 percent of the time and two rollers in use 18 percent of the time.

\*\*\*This equipment performed tasks common to both Craters 5 and 6, which were repaired simultaneously.

- . Select fill delivery.
- . Place, grade and compact select fill.
- . Vibratory compaction.

With the possible exception of the vibratory compaction times, these graphs are based on very few data points and should be updated and revised as more data becomes available.

SECTION IV  
ANALYSIS OF REPAIR QUALITY

1. FIELD TESTING RESULTS

The practice repairs of Craters 1 and 2 were both interrupted after the debris backfill phase was completed. During these interruptions, plate bearing tests, CBR tests, and depth measurements were made on the debris subgrade. The results of these tests are given in Table 6. The CBR results show that the debris backfill was stronger than the worst case CBR 4 to 7 normally expected. However, the CBR was still low enough to have little influence on the expected test results. The values for the modulus of subgrade reaction were also indicative of a low strength subgrade.

The 15-inch depth from the pavement to the subgrade for Crater 1 is significantly less than the 24 inches called for in the crushed limestone repair and may have played an important role in the subsequent failure of the Crater 1 repair (see paragraph 2, below). The 8-inch depth for Crater 2 is exactly as specified for the polymer concrete repair.

TABLE 6. FIELD TESTING RESULTS

	<u>Subgrade Modulus</u>	<u>CBR</u>	<u>Subgrade Depth</u>
Crater 1 - Practice Crushed Limestone Repair	110 pci	Not Available	15 inches
Crater 2 - Practice Polymer Concrete Repair	130 pci	10 to 12	8 inches

2. F-4 LOADCART TESTING RESULTS

Of the six craters repaired at the Small Crater Test, two failed and four were trafficked to 150 coverages (1440 passes). These results are summarized in Table 7.

TABLE 7. F-4 LOADCART TESTING RESULTS

Crater 1 - Practice Crushed Limestone Repair	Failed at 4 passes
Crater 2 - Practice Polymer Concrete Repair	150 coverages
Crater 3 - Timed Crushed Limestone Crushed	150 coverages with one maintenance repair at 100 coverages
Crater 4 - Timed Polymer Concrete Repair	Failed at 10 passes
Crater 5 - Simultaneous Crushed Limestone Repair	150 coverages
Crater 6 - Simultaneous Crushed Limestone Repair	150 coverages

Crater 1 failed due to excessive rutting, as shown in Figure 53. Rutting was evident through T-17 membrane during the first pass and quickly progressed to failure on the fourth pass. The precise cause of the Crater 1 failure is difficult to pinpoint due to a combination of problems with this repair. The probable causes, any one of which may have lead to failure, are poor subgrade compaction, inadequate depth of crushed limestone, and excessive moisture in the limestone. The poor subgrade compaction and inadequate depth were the result of difficulties in handling the large clay chunks which comprised the debris backfill, as discussed earlier in Section III. The excessive moisture was caused by heavy rain during the placement of select fill. Prior testing at Tyndall AFB has revealed that the crushed limestone used at the Small Crater Test tends to rut when the moisture content exceeds 5.5 percent (i.e., the aggregate is freely draining water during handling). The aggregate was clearly wetter than this during the repair of Crater 1.

Crater 2, the practice polymer-concrete repair, developed minor cracks and spalls along the edges of the repair during the early loadcart coverages, as shown in Figure 54. The repair also deflected elastically under the loadcart wheel load. A maximum 0.7 inch of permanent deformation occurred in the main traffic area during the first 50 coverages (480 passes) of the loadcart, increasing only to 0.8 inch after 150 coverages. Hence after the initial deformation of the polymer concrete repair, little further deformation occurred.

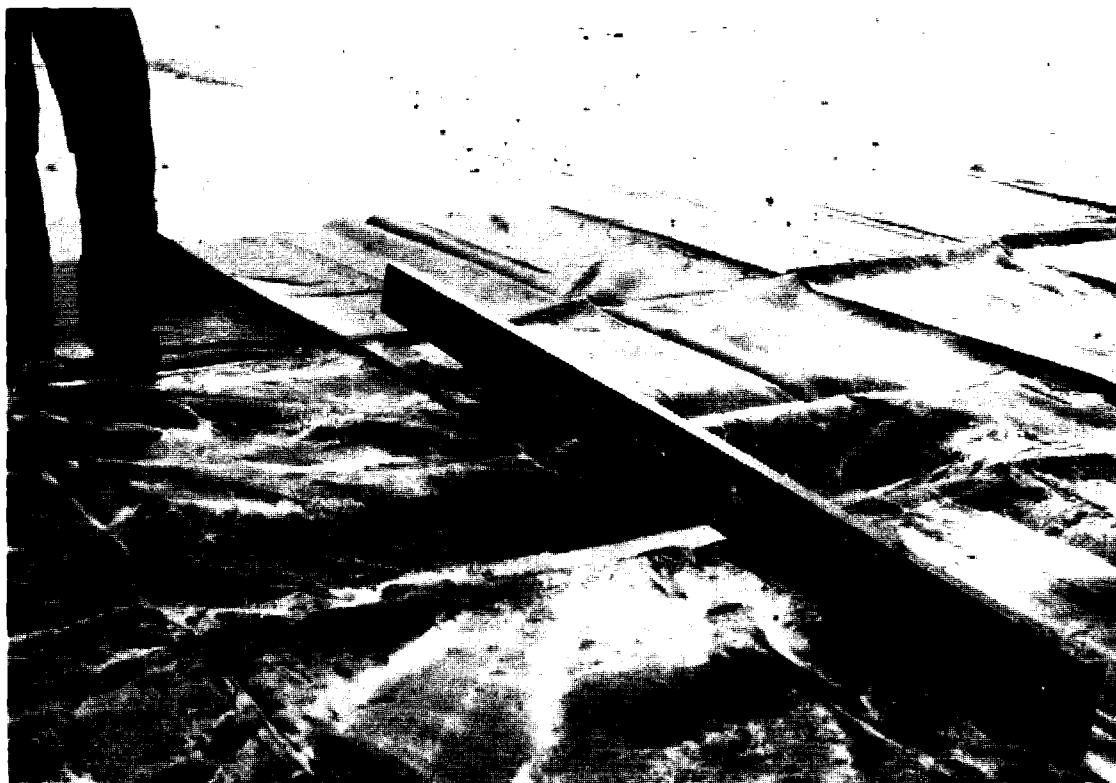


Figure 53. Rutting Failure on Crater 1



Figure 54. Spalled Polymer-Concrete - Crater 2

Crater 3, the timed crushed limestone repair, had some minor problems with shoving of material during F-4 loadcart trafficking. The crushed stone was even pushed out of the crater area onto the surrounding asphalt, creating a small mound on the asphalt lip. After approximately 60 coverages (576 passes) of the loadcart, this bump was removed with shovels. After 100 coverages (960 passes) the crushed limestone had deformed an average 1.7 inches in the main traffic area and was in need of additional material. The loadcart trafficking was interrupted to effect repairs on the patch, as discussed in Section III. Following the repair, loadcart trafficking was resumed. Problems were encountered with the recently-added limestone due to its low moisture content. The crushed limestone tended to shove, creating a definite FOD problem. After 110 coverages (1056 passes) approximately 20 gallons of water were poured on the crushed limestone in a successful attempt to improve its binding characteristics. The repair held up very well thereafter, with trafficking stopping at 150 coverages (1440 passes).

Crater 4, the timed polymer-concrete repair, failed due to material quality. An estimated 20 of the 464 bags of Silikal® lacked the benzoyl peroxide catalyst required for polymerization. As a result of this omission, several areas of the repair failed to harden, causing the unpolymerized material to rise to the surface under the weight of the F-4 tire (Figure 55). This oversight by the manufacturer was due to his internal quality control problems which are now said to have been corrected.

Craters 5 and 6, which were repaired simultaneously, performed very well during loadcart trafficking. Immediately following the test, 10 coverages (96 passes) of the F-4 loadcart were applied. Over the next 16 days the remaining 140 coverages (1344 passes) were applied. The long period of trafficking was due to repeated breakdowns of the loadcart. During the 150 coverages Crater 5 had an average 0.8 inch of permanent deformation in the main traffic area, while Crater 6 had an average of 1.4 inches. Neither crater required an additional repair. The performance of these two crater repairs was exceptional for a crushed limestone repair. The reasons are difficult to pinpoint, but may be due to:

1. Thicker crushed limestone course (36 inches for Crater 5; 18 to 30 inches for Crater 6).
2. Better compaction of the debris backfill and of the crushed limestone due to additional crater repair experience.
3. The cementing effect of limestone over the 17-day traffic period, which included a few periods of rain (normally this is not a factor in our standard short-term testing).

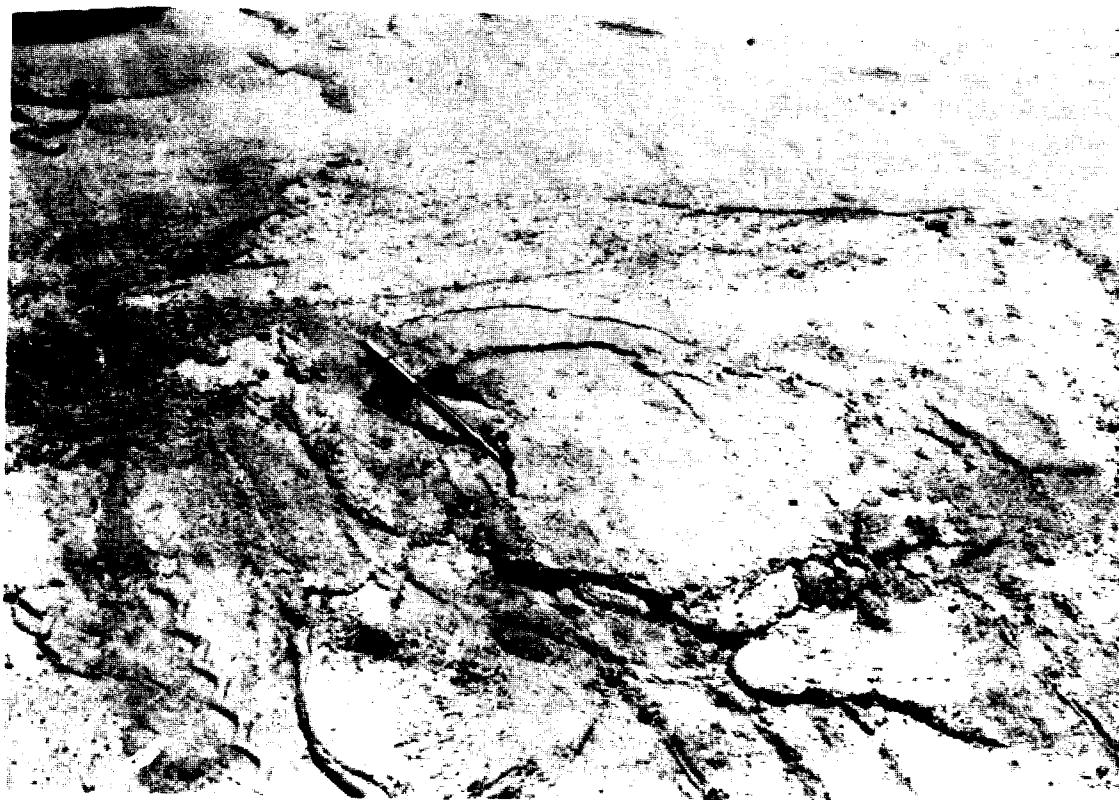


Figure 55. Quality Control Failure on Crater 4

### 3. REPAIR PROFILE ANALYSIS

Figures 56 through 62 show profiles of the repaired craters following completion of the repair and following completion of F-4 loadcart trafficking (if applicable). Crater 3 is broken into two parts to reflect the repair maintenance at 100 loadcart coverages. Also shown on these profiles are the actual values for upheaved pavement slope, maximum upheaval, and maximum sag. Upheaved pavement slope is the change in slope from the original pavement to the upheaved pavement, expressed as a percentage. Maximum upheaval is the greatest change in height from the original pavement to the repaired crater surface. Maximum sag is the greatest difference in height between a piecewise linear approximation of the repair surface and the actual repair surface. The piecewise linear approximation is determined by stretching a taut string across the crater from edge of upheaval to edge of upheaval. The determinations of these values are demonstrated in Figure 63. Ongoing testing is being conducted to determine criteria for surface roughness, and it is expected that slope, upheaval and sag will be among the more important parameters requiring evaluation (Reference 12).

Table 8 summarizes the surface roughness information in Figures 56 through 62. As can be seen in this table, only Craters 2 and 6 completely met the 1.5 percent change in slope criteria used for the Explosive Crater Test, although Craters 1 and 4 were very close to meeting the criteria. Craters 3 and 5 significantly exceeded the slope criteria with slopes up to 4.7 percent. These slopes reflect the crudeness of the 2 x 6-inch straight edge used to measure upheaval. This straight edge at best can only attempt to indicate the location of excessive upheaval; a more reliable and precise method of identifying upheaval is needed.

The transverse and longitudinal upheaval and sag measurements are provided primarily to indicate the relative quality of the crater repairs; no firm criteria has been identified to date. However, preliminary test results with the F-4E aircraft indicate that upheaval less than 2.5 inches is probably tolerable. This criteria was met by all of the repairs except Craters 1 and 6, and it would be an easy matter to remove some crushed limestone to bring these two craters within specifications. Sag is a much bigger problem, with preliminary data indicating that any sag other than an occasional small dip is not acceptable. All of the craters had some sag, ranging from 0.4 inch to 2.6 inches. The requirement for zero sag is impractical for an emergency pavement, and the loss of aircraft due to rough runways is also unacceptable.

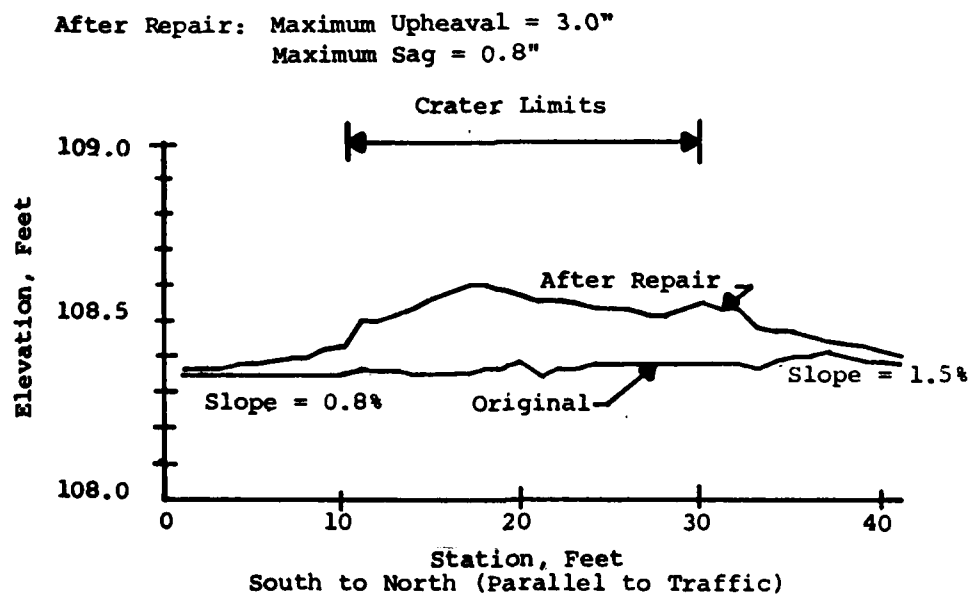
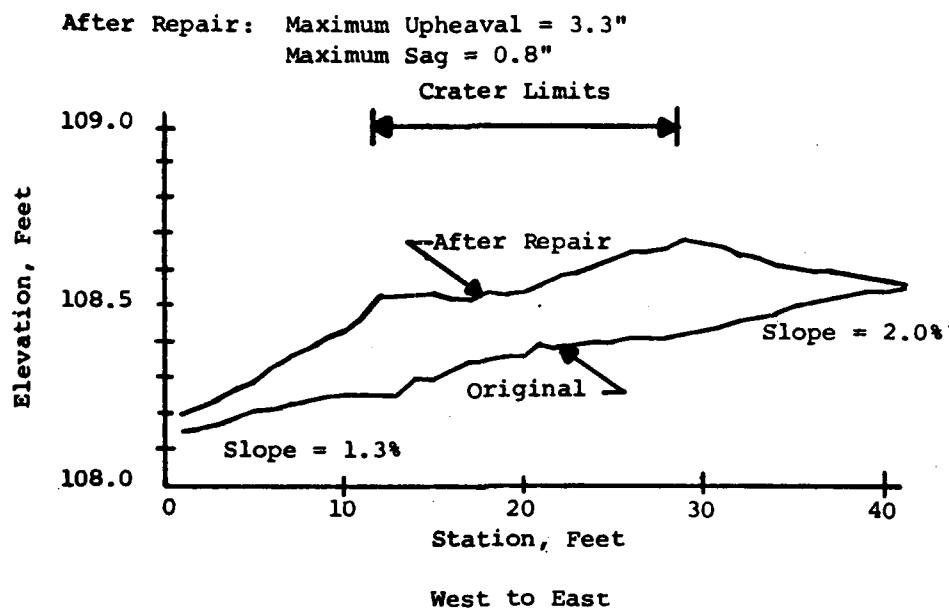
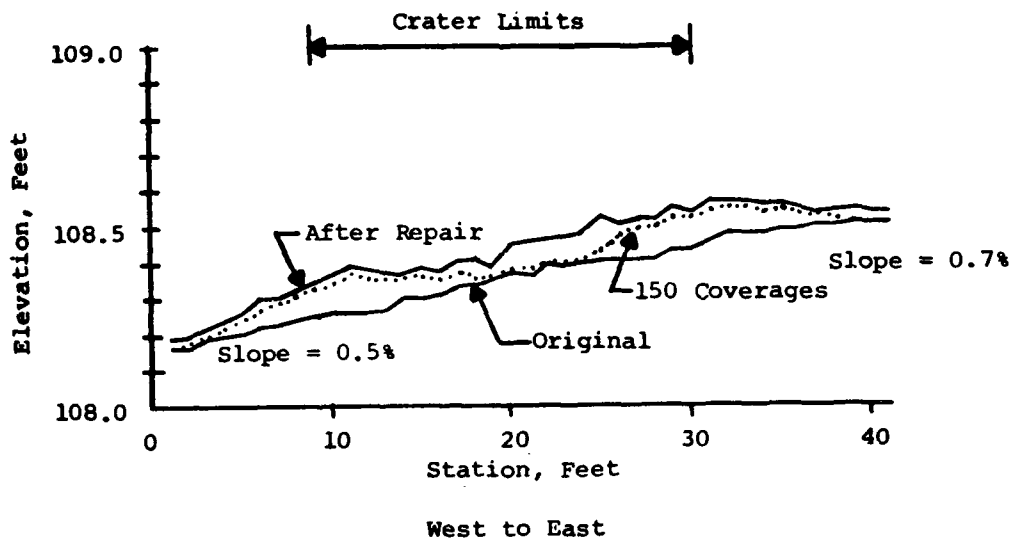


Figure 56. Crater 1 Profiles

After Repair: Maximum Upheaval = 1.6"    150 Coverages: Maximum Upheaval = 1.3"  
 Maximum Sag = 1.0"    Maximum Sag = 1.0"



After Repair: Maximum Upheaval = 1.2"    150 Coverages: Maximum Upheaval = 0.8"  
 Maximum Sag = 0.5"    Maximum Sag = 1.4"

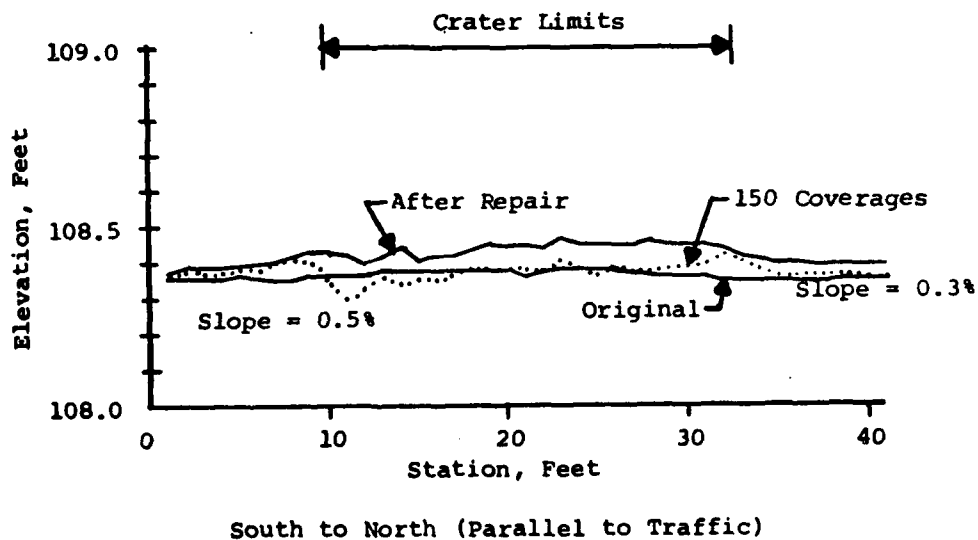
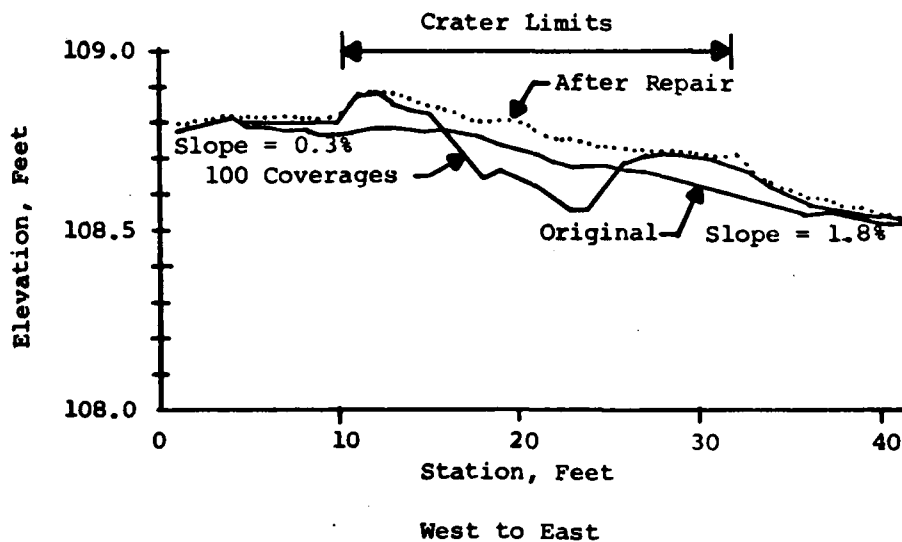
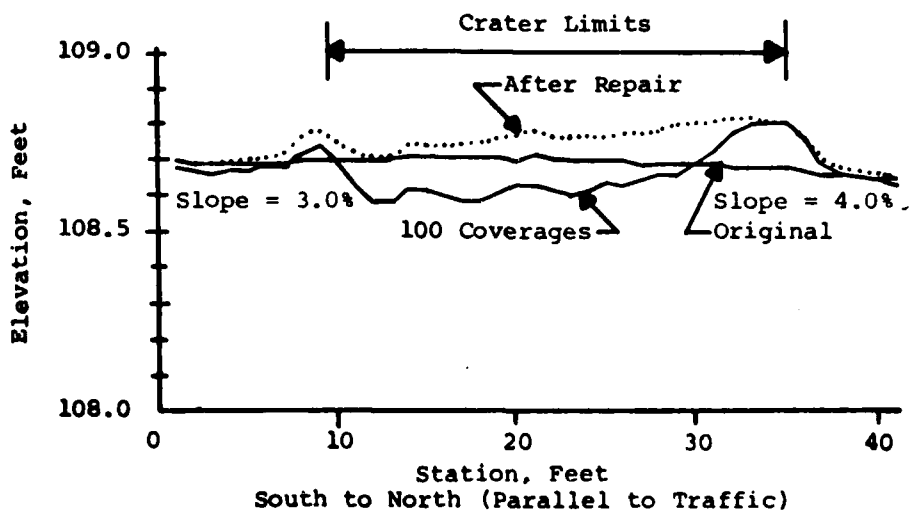


Figure 57. Crater 2 Profiles

**After Repair:** Maximum Upheaval = 1.4"      100 Coverages: Maximum Upheaval = 1.3"  
Maximum Sag = 0.7"      Maximum Sag = 2.6"



**After Repair:** Maximum Upheaval = 1.7"      100 Coverages: Maximum Upheaval = 1.5"  
Maximum Sag = 1.0"      Maximum Sag = 2.2"



**Figure 58. Crater 3 Profiles (Before Maintenance)**

AD-A095 928

AIR FORCE ENGINEERING AND SERVICES CENTER TYNDALL AF--ETC F/6 13/2  
SMALL CRATER EXPEDIENT REPAIR TEST.(U)

AUG 80 K J KNOX

UNCLASSIFIED

AFESC/ESL-TR-80-42

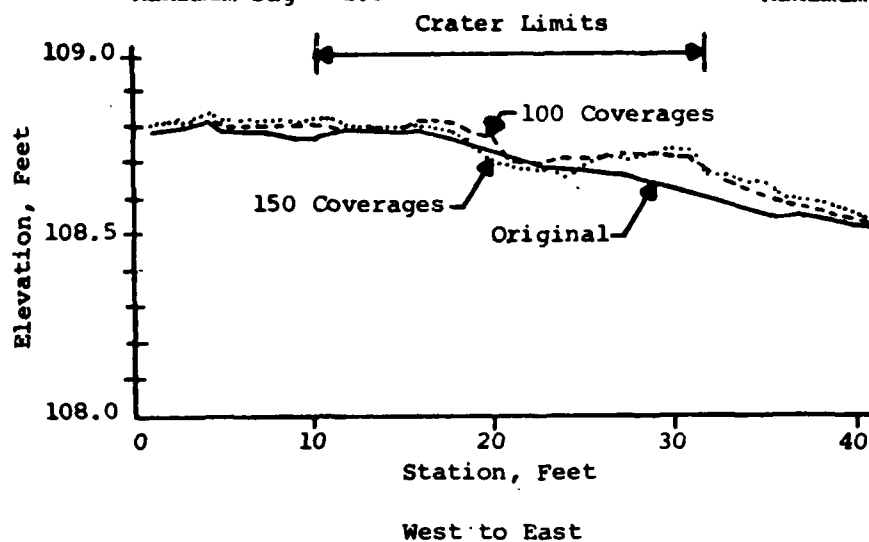
NL

2 of 2  
AD A  
095 928

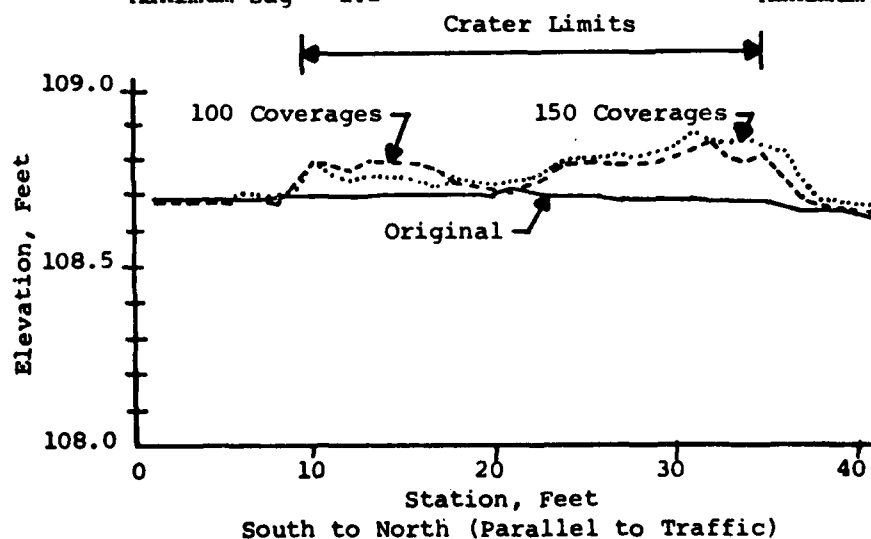


END  
DATE  
FILMED  
4-81  
DTIC

100 Coverages: Maximum Upheaval = 1.3"      150 Coverages: Maximum Upheaval = 1.4"  
Maximum Sag = 1.0"      Maximum Sag = 1.3"



100 Coverages: Maximum Upheaval = 2.0"      150 Coverages: Maximum Upheaval = 2.3"  
Maximum Sag = 1.2"                                      Maximum Sag = 1.3"



**Figure 59. Crater 3 Profiles (After Maintenance)**

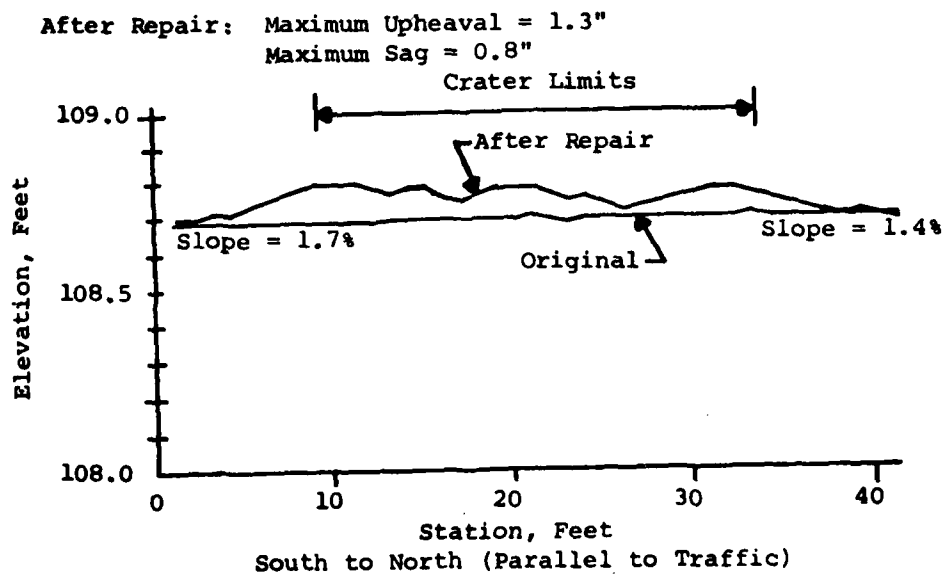
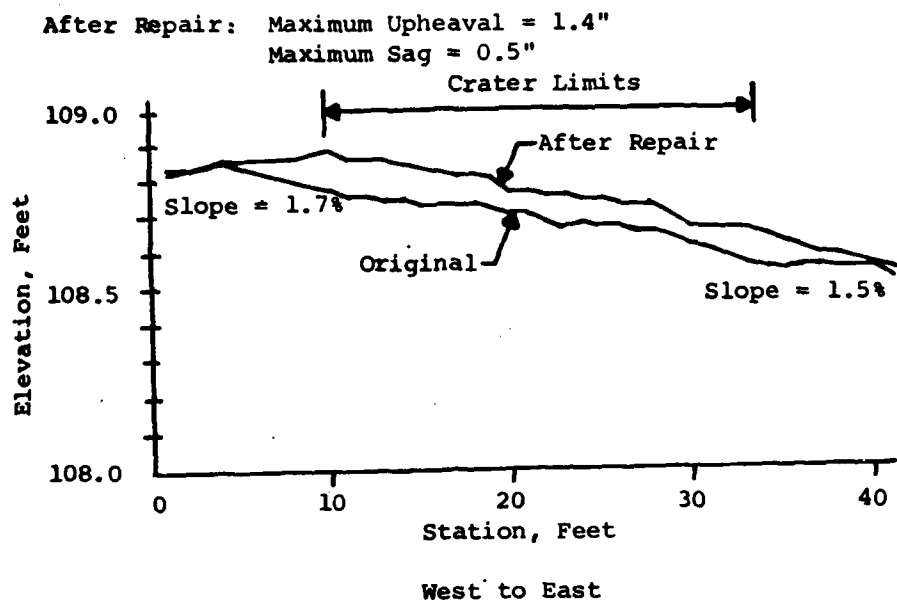
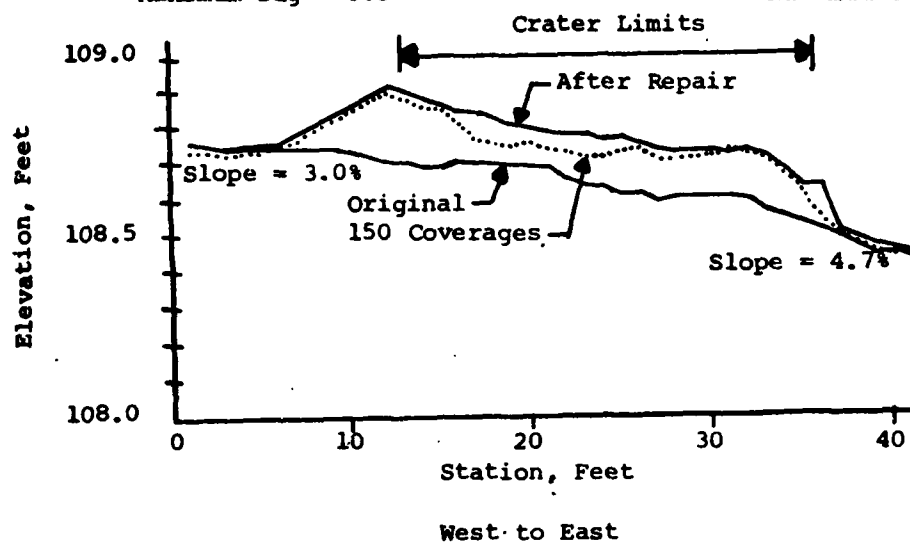


Figure 60. Crater 4 Profiles

After Repair: Maximum Upheaval = 2.5"    150 Coverages: Maximum Upheaval = 2.3"  
 Maximum Sag = 0.5"    Maximum Sag = 1.1"



After Repair: Maximum Upheaval = 1.7"    150 Coverages: Maximum Upheaval = 1.0"  
 Maximum Sag = 0.4"    Maximum Sag = 0.8"

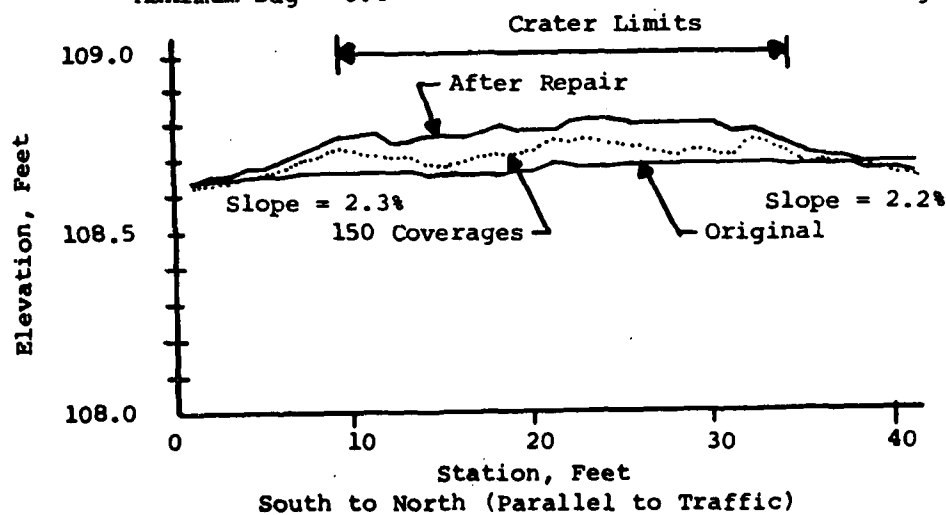
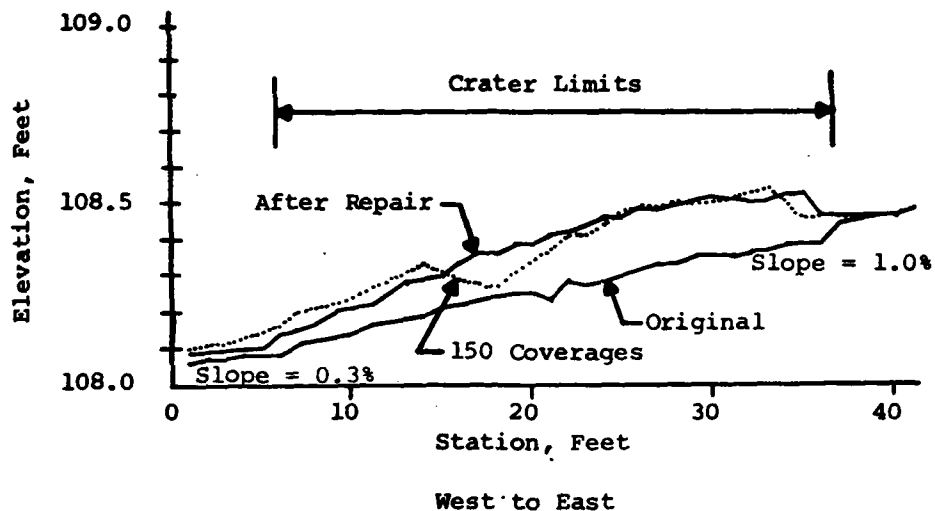


Figure 61. Crater 5 Profiles

After Repair: Maximum Upheaval = 2.2"    150 Coverages: Maximum Upheaval = 2.2"  
 Maximum Sag = 0.7"    Maximum Sag = 1.5"



After Repair: Maximum Upheaval = 2.8"    150 Coverages: Maximum Upheaval = 1.3"  
 Maximum Sag = 1.0"    Maximum Sag = 1.3"

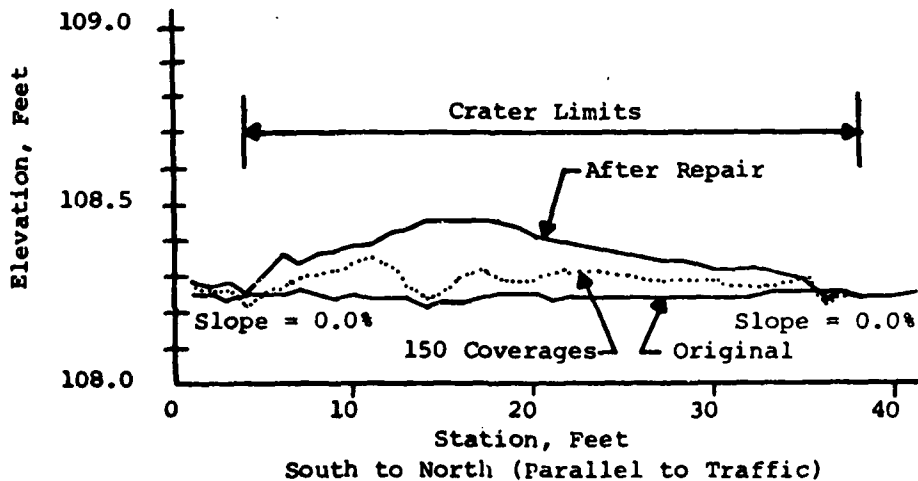


Figure 62. Crater 6 Profiles

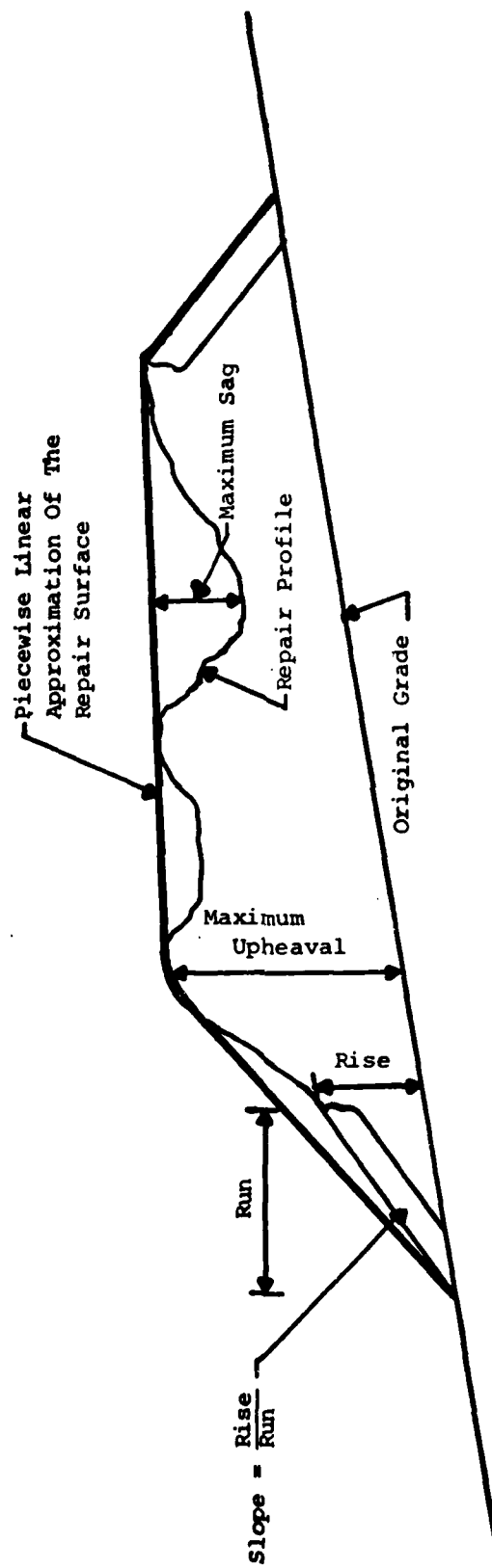


Figure 63. Surface Roughness Measurements

TABLE 8. SURFACE ROUGHNESS MEASUREMENTS

Crater No.	Traffic	Slope (Percent)				Transverse		Longitudinal	
		West (Transverse)	East (Transverse)	South (Longitudinal)	North (Longitudinal)	Upheaval (Inches)	Sag (Inches)	Upheaval (Inches)	Sag (Inches)
1	0 Coverages	1.3	2.0	0.8	1.5	3.3	0.8	3.0	0.8
2	0 Coverages	1.1	0.7	0.5	0.3	1.6	1.0	1.2	0.5
	150 Coverages	1.1	0.7	0.5	0.3	1.3	1.0	0.8	1.4
3	0 Coverages	0.3	1.8	3.0	4.0	1.4	0.7	1.7	1.0
	100 Coverages before maintenance	0.3	1.8	3.0	4.0	1.3	2.6	1.5	2.2
	100 Coverages after maintenance	0.3	1.8	3.0	4.0	1.3	1.0	2.0	1.2
	150 Coverages	0.3	1.8	3.0	4.0	1.4	1.3	2.3	1.3
4	0 Coverages	1.7	1.5	1.7	1.4	1.4	0.5	1.3	0.8
5	0 Coverages	3.0	4.7	2.3	2.2	2.5	0.5	1.7	0.4
	150 Coverages	3.0	4.7	2.3	2.2	2.3	1.1	1.0	0.8
6	0 Coverages	0.3	1.0	0.0	0.0	2.2	0.7	2.8	1.0
	150 Coverages	0.3	1.0	0.0	0.0	2.2	1.5	1.3	1.3

## SECTION V

### CONCLUSIONS

#### 1. GENERAL CONCLUSIONS

a. Well-graded crushed limestone, when properly placed and compacted in a bomb crater, is a field-usable repair capable of supporting F-4 wheel loads without a wearing course.

b. Manually-placed polymer-concrete has too many handling problems and requires too much time for expedient repairs of small craters. However, this technique would be suitable for pavement damage less than ten feet in diameter (scabs).

c. This test has shown that sufficient realistic training of the repair team is the single most effective way to improve the Air Force Rapid Runway Repair capability. Improved equipment without adequate training will result in a poor return on the Air Force's investment.

#### 2. PROCEDURES

a. The thickness of crushed limestone required for the crushed limestone repair should be a minimum of 24 inches, allowing for greater thicknesses if circumstances warrant. The crater chief should prepare small craters for the limestone in the most judicious manner, whether that be to use the debris as backfill or to dispose of the debris and make up the difference with crushed limestone.

b. The crater chief should locate the stockpile of crushed limestone approximately 25 feet from the crater edge to permit repair operations to proceed unhampered.

c. The crater chief must ensure that adequate quantities of repair materials are on hand at the crater. It is much quicker to push leftover repair materials to the runway edge than to wait for additional material to be delivered to the crater site.

d. Silikal® polymer-mortar should be placed and screeded within 5 to 10 minutes after mixing (assuming ambient temperatures greater than 80°F) to avoid problems with rapid set time. Extra screeds should also be available to replace screeds caked with mortar.

e. The method for identifying upheaved pavement used in the Small Crater Test does not reliably identify all upheaval. This problem may be due to the crudeness of the straight edge used in the test.

### 3. EQUIPMENT

a. The loader is the most effective piece of equipment in the RRR kit. Its major drawbacks are an inability to clean loose debris on the crater edge and a lack of sufficient power to remove upheaved pavement.

b. The dozer is too large and awkward to use for cleaning out a small crater, or for placing and compacting debris backfill in a small crater.

c. No equipment currently in the RRR kit can satisfactorily remove upheaved pavement around a small crater. The dozer blade is too big, and the loader (outfitted either with a bucket or with forks) lacks sufficient power. The dozer's ripper tooth is marginally capable of removing upheaved pavement, but this operation requires too much time.

d. The hand-held radios used in the Small Crater Test are completely inadequate. New communication equipment is needed by the repair team to efficiently use equipment and manpower resources.

SECTION VI  
RECOMMENDATIONS

1. Equipment should be identified and procured for the RRR kits which is capable of removing upheaved pavement and cleaning the debris from the walls of small craters.
2. For the crushed limestone repair:
  - a. An investigation into methods to make the repair more moisture tolerant should be undertaken.
  - b. The requirement for FOD covers and candidate FOD cover systems should be thoroughly investigated.
  - c. Actual aircraft testing should be performed over repaired craters.
  - d. The availability of crushed limestone at locations where RRR kits are stored should be studied.
  - e. The suitability of other types of crushed stone (granite, basalt, etc.) should be determined.
3. For the polymer-concrete (Silikal®) repair:
  - a. A mechanized system to level uniform aggregate, mix and place the polymer concrete, and screed the concrete should be developed and tested for small craters.
  - b. An investigation into methods to make the repair more moisture tolerant should be undertaken.
  - c. Improved packaging should be developed to facilitate handling the pallets and to aid in mixing the concrete.
  - d. Improved quality control should be introduced to insure that the polymer-concrete will achieve adequate strength within the prescribed time limit.
4. Intensive realistic training of RRR teams should be undertaken. This training should include the repair of actual craters of varying sizes and the simultaneous repair as often as possible. Each operator should be trained on more than one type of equipment.
5. Surface roughness criteria and field evaluation techniques should be improved.
6. A communications system employing headphone-type radios should be developed for key members of the repair team.

## REFERENCES

1. Air Force Regulation 93-2, Base Recovery Planning, Department of the Air Force, Washington DC, 11 December 1979.
2. Hokanson, Lawrence D. and Raymond S. Rollings, Jr., Field Test of Standard Bomb Damage Repair Techniques for Pavements, AFWL-TR-75-148, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.
3. Rollings, Raymond S., Laboratory Evaluation of Expedient Pavement Repair Materials, CEEDO-TR-78-44, Civil and Environmental Engineering Development Office, Tyndall Air Force Base, Florida, June 1978.
4. Rollings, Raymond S., Summary Report on Amalgapave Testing January 1976 - August 1978, ESL-TR-79-07, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, April 1979.
5. McNerney, Michael T., Interim Field Procedure for Bomb Damage Repair Using Crushed Stone for Crater Repairs and Silikal® for Spall Repairs, ESL-TR-79-01, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, April 1979.
6. Rollings, Raymond S., Interim Report of Field Test of Expedient Pavement Repairs (Test Items 1-15), ESL-TR-79-08, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, March 1980.
7. McNerney, Michael T., Final Report of Field Test of Expedient Pavement Repairs (Test Items 16-35), ESL-TR-80-51 (DRAFT), Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.
8. Brown, D.N. and O.O. Thompson, Lateral Distribution of Aircraft Traffic, MP-S-73-56, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, July 1973.
9. Air Force Manual 89-3, Materials Testing, Department of the Air Force, Washington DC, 6 February 1971.
10. Knox, Kenneth J., Evaluation of Vibratory Rollers for Bomb Damage Repair, ESL-TR-80-43 (DRAFT), Air Force Engineering and Services Center, Tyndall Air Force Base, Florida.
11. Rosser III, T.B. and S.L. Webster, Evaluation of Nuclear Methods of Determining Surface In Situ Soil Water Content and Density, MP-S-69-15, US Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, April 1969.

12. Caldwell, Lapsley R., and Fredrick J. Jacobsen, Interim Guidance for Surface Roughness Criteria, ESL-TR-79-37, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, October 1979.

13. Compaction Equipment Specifications, Equipment Guide-Book Company, Palo Alto, California.

## APPENDIX A

### EQUIPMENT PERFORMANCE SPECIFICATIONS

Performance specifications are included in this appendix for the following equipment:

1. International Harvester TD-20 (Series B)  
Crawler Tractor (Figure A-1).
2. Fiat-Allis 745-C Wheel Loader (Figure A-2).
3. RayGo Rascal 410-A Vibratory Roller (Figure A-3).

1. INTERNATIONAL HARVESTER TD-20 (Series B) CRAWLER TRACTOR

. Horsepower (Engine horsepower at flywheel at rated rpm)	160
. Maximum Travel Speed (miles per hour)	
Forward. . . . .	6.0
Reverse. . . . .	6.8
. Drawbar Pull (pounds). . . . .	87,000
. General Dimensions (inches)	
Length, overall . . . . .	164.4
Width, overall (20-inch shoe). . . . .	94
Height, grouser tip to highest point, less pipes . . . . .	95
Height, grouser tip to top of exhaust pipe . . . . .	128.5
. Weight (pounds, approximate)	
Shipping, with regular equipment. . . . .	30,300
Operating, including fuel and water. . . . .	31,000



Figure A-1. International Harvester TD-20 Dozer

## 2. FIAT-ALLIS 745-C WHEEL LOADER

. Horsepower (Engine horsepower at flywheel) . . . . .	202
. Maximum Travel Speed (miles per hour)	
Forward . . . . .	20.0
Reverse . . . . .	7.3
. 4-in-1 Bucket Capacity-Rated (cubic yards) . . . . .	3.5
. Breakout Force - Approximate (pounds) . . . . .	36,000
. General Dimensions - Approximate (inches)	
Length, overall (bucket on ground) . . . . .	290
Width . . . . .	118
Height. . . . .	140
. Weight, Operating (pounds, approximate) . . . . .	40,400



Figure A-2. Fiat-Allis 745-C Loader

### 3. RAYGO RASCAL 410-A VIBRATORY ROLLER

. Horsepower (at 2500 rpm) . . . . .	88
. Maximum Travel Speed (miles per hour)	
Forward. . . . .	8.0
Reverse. . . . .	8.0
. Dynamic Force (pounds) . . . . .	27,000
. Vibration Frequency Range (vibrations per minute). .	1110-1500
. General Dimensions (inches)	
Length, overall . . . . .	207
Width, overall . . . . .	104
Height (including muffler). . . . .	86
Drum Diameter . . . . .	59
Drum Length . . . . .	84
. Weight, Shipping (pounds, approximate) . . . . .	21,400



Figure A-3. RayGo Rascal 410A Vibratory Roller

## APPENDIX B

### CRUSHED LIMESTONE REPAIR TIME ESTIMATES

Crushed limestone repair time estimates are given in this appendix for the following:

1. Crater Preparation Times for Crushed Limestone Repair (Figure B-1).
2. Times for Select Fill Delivery - Crushed stone Repair (Figure B-2).
3. Times to Place, Grade and Compact Select for Crushed Limestone Repair (Figure B-3).
4. Determination of Times for Vibratory Comp. (Figure B-4).

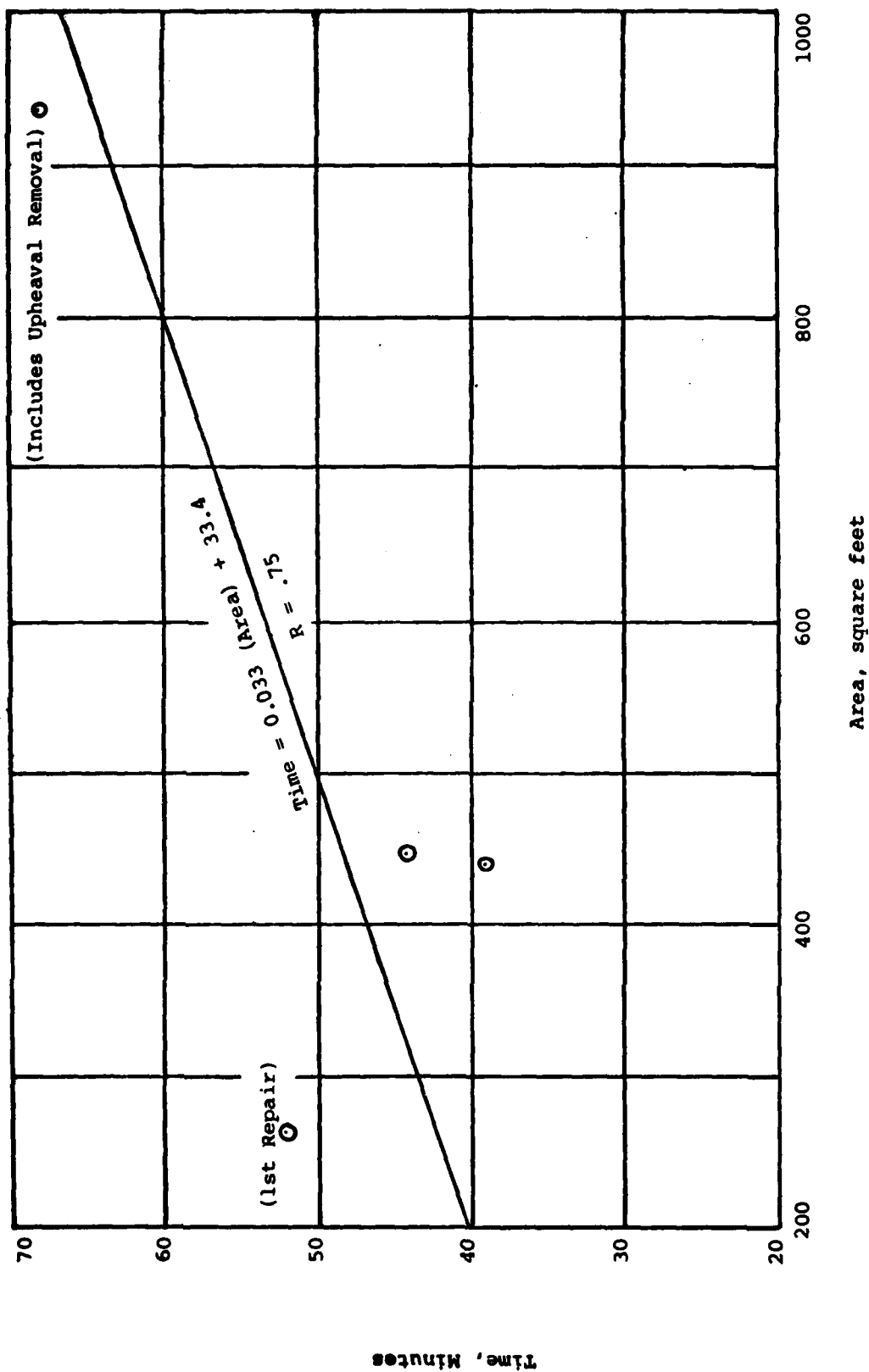


Figure B-1. Crater Preparation Times for Crushed Limestone Repair

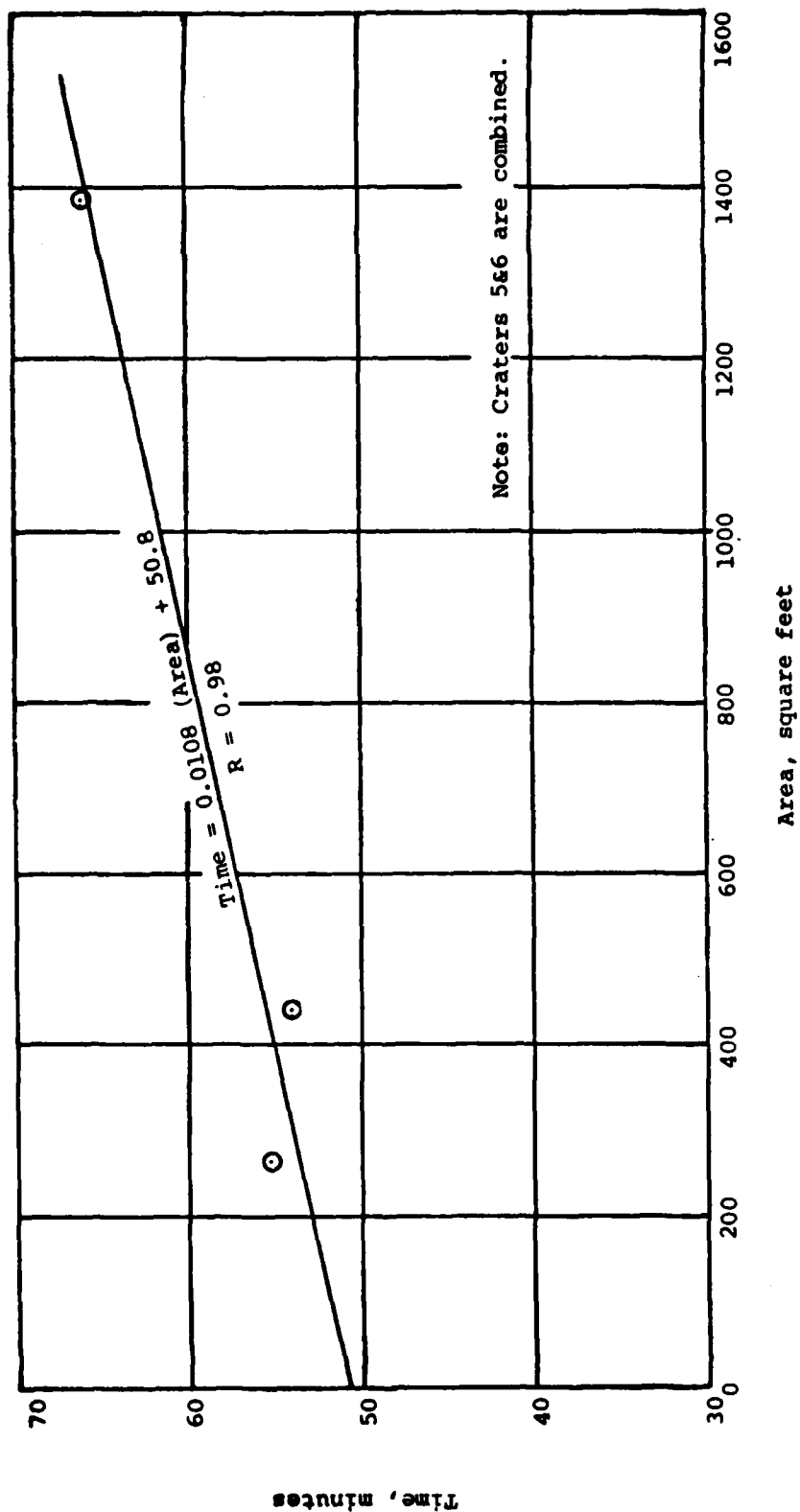


Figure B-2. Times for Select Fill Delivery - Crushed Limestone Repair

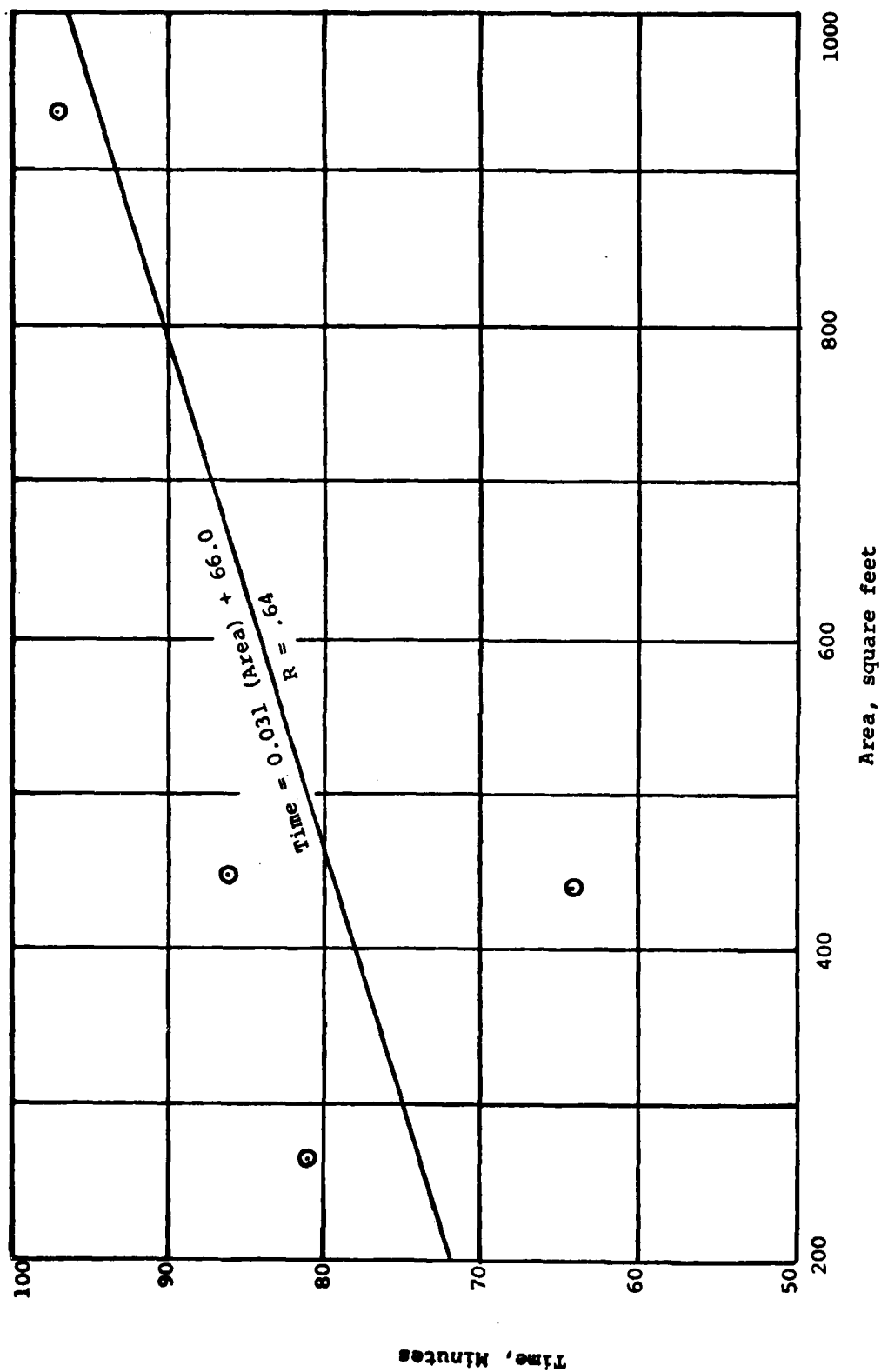


Figure B-3. Times to Place, Grade and Compact Select Fill for Crushed Limestone Repair

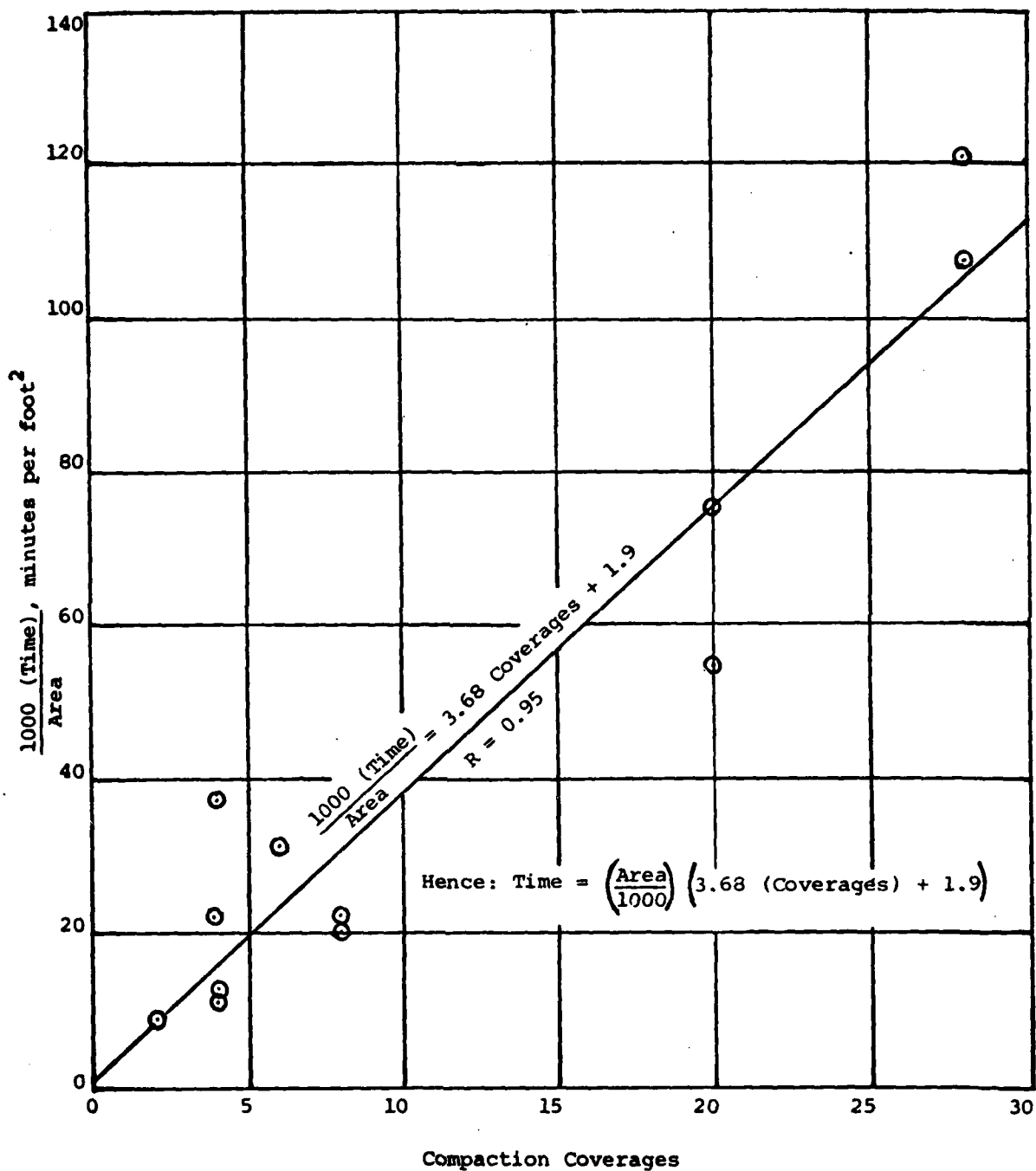


Figure B-4. Determination of Times for Vibratory Compaction

# INITIAL DISTRIBUTION

DTIC-DDA-2	12
HQ AFSC/DLWM	1
HQ AFSC/SDNE	1
HQ AFSC/DEE	1
HQ AFSC/DEM	1
HQ USAFE/DEMY	2
HQ USAFE/DEM	2
HQ USAFE/EUROPS (DEXD)	2
AFATL/DLJK	1
AFATL/DLODL (Tech Library)	1
AD/IN	1
USAFTAWC/RX	1
USAFTAWC/THL	1
USAFTAWC/THLA	1
EOARD/LNI	2
SHAPE TECHNICAL CENTER USRADCO	1
HQ PACAF/DEM	2
HQ TAC/DEE	2
HQ TAC/DRP	1
HQ TAC/DEPX	1
HQ AUL/LSE 71-249	1
HQ SAC/DE	1
HQ SAC/DEE	1
HQ SAC/DEM	1
USN Civil Engineering Laboratory	2
US Naval Construction Battalion Center	1
NAVEODFAC	1
HQ ATC/DED	1
HQ ATC/DEE	1
HQ MAC/DEM	1
HQ AFESC/DEO	1
HQ AFESC/DEMP	1
HQ AFESC/TST	1
HQ AFESC/RDC	5
HQ AFESC/RDCR	10
HQ AFESC/RDCT	2
HQ USAFA/DFEM	1
USAE Waterways Experiment Station/WESGF	2
HQ USAF/LEEX	1
HQ USAF/LEYW	1
HQ USAF/RDPX	1
AFWAL/FIEM	1
AFWAL/FIBE	1
HQ AFLC/DEMG	1
AFIT/DET	1
AFIT/LDE	1
AFWAL/MMXE	2
HQ AFLC/DEE	1
AFATL/DLONR	1

DATE  
FILMED  
-8